CORN AND GRAIN SORGHUM YIELD AND MINERAL NUTRITION IN MULTICROPPING SYSTEMS

BY

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A DISSERTATION PRESENTED TO THE GRADUATE
COUNCIL OF THE UNIVERSITY OF FLORIDA IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1984

ACKNOWLEDGEMENTS

There were many people who had a hand in the completion of this work and deserve a special mention. I would like to express my gratitude to my advisor, Dr. Raymond N. Gallaher, for his valuable contribution to my education outside of the classroom, and to his wife, Wanda, for her hospitality and willingness to pitch in when help was most needed.

My committee members, Dr. W.G. Blue, Dr. V.E. Green, Dr. P.E. Hildebrand, and Dr. G.M. Prine, also made important contributions to my education and the completion of this work. I am also deeply indebted to several people for their assistance in collecting and analyzing the several thousand plant and soil samples that provided the data for this study. I would like to thank Sonny R.Thompkins and Glenn P. Sappie for their work in the field; Shawn R. Costello and Loretta H. Tennant for their assistance in the laboratory; David Block for his computer advice and Laura Robertson for typing the manuscript.

Lastly, but most importantly, I would like to give a special thanks to my wife, Juanita, for her moral and financial support through yet another two years of late nights, working weekends, and missed vacations.

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April 1984

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Major Department: Agronomy

Legumes in multicropping systems may be utilized as mulch, green manure, grain, or forage. Erosion losses may be reduced, pest cycles hindered, and cycling of soil nutrients may be beneficial effects of succession cropping legumes with cereal grains. In addition, a portion of the N fixed by the legume may become available to subsequent crops.

This investigation was designed to determine 1) the quantity of N fixed by crimson clover (*Trifolium incarnatum* L.) and lupine (*Lupinus angustifolius* L.) and the portion of this quantity recovered by corn (*Zea mays* L.) and grain sorghum (*Sorghum bicolor* L. Moench); 2) optimum N fertilization rates for corn and grain sorghum when following a legume; 3) effect of tillage on N mineralization of the legume; and 4) effect of removing the legume residue as a forage on grain yields and N fertilization requirements for corn and grain sorghum.

Total N fixed by the legumes was sufficient for maximum corn and grain sorghum seed production; however, only a portion of the total was recovered. Grain sorghum dry matter (DM) and seed yields responded to additional inputs of 25 to 50 kg N/ha when clover residue was left in the field as a mulch or incorporated as a green manure while 75 to 100 kg N/ha were needed if legume residue was removed. Incorporating the legume residue was not necessary to release organic N but appeared to hasten mineralization. Slightly more applied N was necessary for no-tillage (NT) grain sorghum to attain yields equal to conventional-tillage (CT) treatments for two of the four experiments conducted in this study.

Applied N increased nutrient concentrations of P, Ca, Mg, Fe, Zn, Mn, and Cu and decreased K in the diagnostic leaf of grain sorghum when following either crimson clover or lupine. Grain N and whole plant N content of grain sorghum also increased with applied N, as did grain nutrient levels exceeding 100 kg/ha, correlating to diagnostic leaf N levels of 3.35% or higher. Approximately 2.9% N was needed in the diagnostic leaf of grain sorghum for maximum grain yields.

Nutrient cycling was improved by including a legume in succession with corn and grain sorghum. In addition to reduced erosion and leaching losses, substantial quantities of organic N were added to the system. Soil balances of P were positive under the systems investigated while K, Ca, and Mg were largely unaffected. Soil N balance was positive at low N rates if legume residue was left but became negative as rate of applied N increased.

CHAPTER I
LITERATURE REVIEW

Introduction

The world's ever-growing population is placing an increasing demand on agricultural scientists and producers. The challenge to this group, however, far exceeds the increase of total food procution. As many of the world's hungry and malnourished people do not live in areas of high agricultural technology and production, there must be rapid improvements in both the distribution of current food production and development of new technologies applicable to those areas of the tropics and subtropics where the population centers occur.

Due to a lackluster world economy and dramatic increases in the cost of fossil fuels over the past 10 years, producers in developed nations are being challenged to increase yields and nutritional quality of agricultural products while decreasing energy inputs. A similar problem faces their counterparts in developing countries, to maximize agricultural output while keeping fossil fuel inputs to a minimum. As most of the world's potentially productive arable land is already under cultivation, the present agricultural systems must be refined to meet these increased demands. Fortunately there is much room for improvement in many of today's systems, but only carefully and appropriately directed research will provide data that will be useful in devising the necessary improvements with concurrent decreases of inputs.

The agricultural systems developed under the influence of comparatively high commodity prices and low fossil fuel prices were in many ways wasteful and damaging to the environment. Over-tillage led to weed-free fields but also dramatically increased soil erosion and lowered the long-term productivity of many of the best soils. In many areas, heavy pesticide application led to extremely resistant races of insects and diseases as well as arousing public concern over the subsequent pollution of water supplies. Likewise low chemical fertilizer prices encouraged growers to ignore declining soil organic matter levels and nutrient cycling within their systems. Groundwater pollution, inefficient fertilizer application, and the development of crop varieties that require very high fertility levels have all been by-products of this high fossil fuel-input technology developed over the past 30 years.

How then can the agricultural community address the immense problem of increasing outputs while decreasing inputs? Can the erosion of today's productive soils be stopped and the already highly weathered soils of the tropics be made to feed the hungry masses that dwell on them?

There are, fortunately, several promising pathways to pursue. Perhaps ironically some of the best alternatives are founded in ancient agricultural practices that may be revived and refined to fit today's systems. The purpose of this study is to investigate one such practice, green manuring with legumes in multicropping systems.

Legumes for Green Manure

History

Legumes have been cultivated in cropping systems since pre-recorded history. Remains from ancient civilizations and Biblical references indicate that beans and lentils have been grown in rotation with cereal grains for thousand of years. The first reference to using legumes as a green manure (legumes grown for their soil improving qualties or as cover crops which are plowed in at the end of the growing season; Dalrymple, 1971) for soil-building comes from the Romans in the second century BC (Davis et al, 1940). The practice was again advocated in Europe during the Middle Ages. For two centuries after the colonization of the United States, the production of legumes for green manure was not a common practice, even though early American farmers mined the new agricultural lands of their native fertility. About the middle of the 19th century, however, crop yields were declining and soil erosion was becoming a recognized problem in the southeastern US. Hairy vetch (Vicia villosa Roth) was first introduced to the U.S. in 1847 but met with limited success (Scott, 1929). It was reintroduced in 1870 along with Austrian winter pea (Pisum sativum subsp. avense L. Poir) and crimson clover (Trifolium incarnatum L.) as a winter legumes for wheat (Triticum aestivum L.) and corn (Zea mays L.) systems, this time with more success. Frequent mention of winter-cropping legumes started to appear in the literature in the 1890's and by 1920 almost every extension office in the southeastern U.S. was recommending winter legumes for soil-building and erosion control.

Harlan (1912) reported 500 kg/ha improvement in barley (Hordeum vulgare L.) yields even 2 years after clover had been plowed under. The Alabama State Experiment Station established permanent winter legume plots in 1896 and by 1923 had accumulated 27 years' of data of double-cropping and intercropping corn (Zea mays L.) and cotton (Gossypium hirsutum L.) with legumes (Funchess, 1923). They reported that a good stand of hairy vetch or crimson clover added 50 to60 kg N/ha although they needed lime and P for good establishment. When cotton was intercropped with vetch following a cowpea (Vigna unguiculata L.) green manure crop, cotton yields were triple those of monocropped cotton.

Work in the early part of the century was conducted mainly with hairy vetch, several types of clover, Austrian winter pea, soybean (Glycine max L.) and peanut (Arachis hypogaea L.). Blair (1930) advocated winter cropping of crimson clover in North Carolina while Scott (1929) suggested velvetbean (Stizolobium deeringianum L.), Florida beggarweed (Desmodium tortuosum L.) and crotalaria (Crotalaria spectabilis L.) for Florida farmers. During this period, establishing a good stand of the legume was difficult as most soils did not contain native Rhizobium of the correct strains and inoculation of seed was accomplished by mixing several hundred kilograms of topsoil from an established stand with the planting seed. By the mid 1930's, however, Wasson (1937) indicated that many Louisiana growers were using packaged inoculum. This technology and consistent claims of improved corn and cotton yields resulted in a 60% increase of Louisiana acres cropped to winter legumes in just 1 year.

Following World War II, inorganic N fertilizers invaded the agricultural market and immediately became very popular. Declining N prices during the 1950's and 1960's corresponded to a drastic reduction in legume research except perhaps in pasture and forage systems. It is interesting to note that price of N was approximately 44 cents/kg at the turn ot the century (Harlan, 1912), close to present day price of N in anhydrous ammonia. During the late 1950's N prices dipped below 11 cents/kg.

When petroleum prices soared in 1973 so did N fertilizer prices. The changing economics of inorganic N use coupled with a growing national concern over soil erosion losses has sparked yet another comeback for winter-cropping legumes in the Southeast. The fact that N represents almost 68% of the fossil fuel energy for NT (no-tillage) corn production has led to a search for winter legumes that can fix large amounts of N in addition to raising soil OM levels for improved water and nutrient-holding capacities.

N-fixation and Factors Affecting It

The parameters affecting legume yield and quantities of N fixed are varied and complex. Since it is the symbiotic relationship between a specific rhizobium strain and the legume, management success of the system depends largely on the extent of inoculation by the bacteria and the conditions affecting N fixation within the nodule. Once proper care has been taken to inoculate the legume effectively, the amount of N fixed will be determined by (a) the amount of nodule tissue formed; (b) the duration of the activity of the nodule; (c) the capacity of the particular rhizobium strain; and (d) environmental factors that affect the mechanisms of N fixation (Whiteman, 1980).

The amount of nodule formation is closely regulated by the host to meet its N requirements. As the leaf N concentration of most of the major green manure legumes differs by a percentage point or so, if environmental factors are favorable the total N required by each of these crops is largely determined by the dry matter production of each. It should be noted, however, that efficiency of N fixation may vary greatly among rhizobium strains.

The duration of nodule activity is dependent on the species of legume and the length of the growing season. Most winter legumes used for green manuring are allowed to grow as long as possible to maximize N fixation. However, maximum N production is rarely attained as the legume is killed or plowed under before maturity so that planting of the spring crop may still be timely.

External factors affecting quantities of N fixed will be the major determinant of the success of the legume once proper inoculation has been achieved. Soil temperatures for maximal N fixation in legumes in the Southeast range between 20 to 25 C and the process will be minimal at 5 to 10 C (Whiteman, 1980). Hot, dry soils may kill the inoculant as may waterlogging. High soil N levels will inhibit nodule formation as will low levels of P and S. Unless the rhizobium strain originated in the tropics, it is usually not very acid-tolerant (largely because of Ca and Mg deficiencies) and liming to a pH of at least 6.5 may be necessary.

Although N fixing potentials of several legumes are dealt with in a subsequent section, it may be stated that many of the green manure crops utilized today will fix between 100 to 200 kg N/ha. Before incorporating a legume into a system, though, a grower must weigh the advantages and disadvantages of doing so. Besides considering the price of N added by the legume against the price of establishment, the grower must consider the economic benefits of added OM and reduced erosion. Although it is difficult to assign a monetary value to these benefits, yield increases in subsequent crops are well documented. Mulched treatments of vetch and rye (Secale cereal L.) in South Carolina increased soil OM levels from 1.5% to 2.6% and soil N from .047% to .069% after 10 years (Beale et al., 1955). The added OM serves as a binding site for water and cationic nutrients as well as improving the soil tilth. Gallaher (1977) also reported increased water availability to corn and soybeans when NT planted into a rye mulch as opposed to rye stubble. These parameters may be just as important as added N, especially in the coarse-textured soils of the Southeast. No-tillage planting of the spring crop into the legume serves to increase these benefits further, particulary moisture conservation.

There are disadvantages to the green manuring practice, however, that have somewhat held back its acceptance. With many of the present legumes the cost benefit of additional N only offsets the cost of purchasing and planting the seed. Fast-growing, early-maturing species that will fix N all winter are still being sought. Early planting of spring crops for maximum yields may cut short the purpose of a legume program if it must be killed before an adequate amount of N has been fixed. Several studies also suggest that green manure crops should be killed at least 2 weeks prior to spring planting to allow some decomposition and soil moisture recharging (Blair, 1930; Reynolds et al, 1958). In a long-term Texas study, winter legumes increased subsequent corn and cotton yields only in wet years as moisture, not available N, is normally the yield-limiting factor there and the legumes growing actively through the winter depleted soil moisture reserves. In addition, decomposition of the green manure and subsequent N release was much slower under extremely dry soil conditions.

Adding a new crop to a farming system also poses some management questions. The higher pH and P requirements of the legume may require more frequent fertilizer applications. Broadleaf weeds and perennial grasses may also be difficult to control in legume stands, especially in NT systems. On the other hand, some evidence suggests that certain winter legumes may lower nematode populations, especially those that are severe in grass crops (Soffes, 1981).

In many developing nations, there may be a strong predjudice against green manuring as it is considered wasteful to incorporate any crop that is viewed as valuable animal feed (Whyte et al., 1953). In addition, machinery required for legume incorporation or NT planting is not available. In this situation, however, it may still be economically feasible to cut the legume for hay once or graze it lightly and allow a couple of weeks for regrowth before manuring. Even though the legume tops usually contain about 80% of the total plant N, some will still remain in the soil and a large portion of that removed could still be recycled by applying the manure from the animals back to the field. In many farming systems winter forage production will be the primary goal of winter legumes and any residual soil N will merely be a bonus.

Many plant scientists believe that the most efficient place for a legume in a multicropping system is the normal "off season". Growing the legume by itself for maximum DM and N production seems more feasible than intercropping grasses and legumes. Whyte et al. (1953) reported very little N is exuded by legume roots during the growing season; hence, there is little available N for companion grass crops until there is decompostion of the legume residue at the end of the season and organic N is mineralized. Wahua and Miller (1978) and Kang et al. (1981) reported no or very little total N increase in grasses grown in conjunction with legumes. It is quite possible that established systems reporting a significant yield response to intercropping may be utilizing mineralized N from the decay of the previous year's legume.

Specific Systems

Hairy Vetch

Of all the winter legumes tested for their potential as green manure sources for multicropping systems in the Southeast, hairy vetch has probably shown the most promise. The advantages of hairy vetch are that it is a prolific N producer and is somewhat easier to establish than other legumes. Vetch seed may be broadcast into shredded cornstalks and still establish a good stand even without being disced in. A Delaware farmer usinga vetch no-tillage (NT) corn system estimated that the vetch supplies 50-60 kg N/ha the first year and perhaps close to an equal amount the second year. Mitchell of the Delaware Extension Service estimates that a 50 cm high stand of vetch may contribute as much as 200 kg N/ha over a 3 year period. About 120 kg would be available the first year, and 40 kg each of the next 2 years (Prog. Farmer, Aug. 1982).

The vigorous nature of vetch seedlings also predisposes the crop to overseeding into maturing summer crops such as corn. Winter growth may then commence before corn harvest. This may be critical not only in the northern regions of winter legume cropping but also in the South where spring crops often attain the best yield if planted in late February. Hairy vetch matures later than some other legumes and to date this may be its most serious drawback. Blair

(1930) reported that although hairy vetch was a much better reseeder than crimson clover, it was not ready for manuring until about 2 weeks later than the clover. Since vetch will continue to grow past optimum spring crop planting dates, it must be killed in the spring. Plowing or disking the mulch to incorporate it and prepare the seedbed has been the traditional treatment; however the new NT planters have given another option. The vetch may be killed fairly cheaply with paraquat (1,1',dimethyl, 4,4' bipyridinum present as the dichloride salt) or 2,4-D (2,4-dichlorophenoxy acetic acid). The herbicide program should be designed to not only kill the vetch but also to serve as the initial herbicide treatment for the spring crop. If corn is to be grown, a residual such as atrazine (2-chloro-4-ethylamine-6- isopropyl-amine-s-triazine) to control grasses may be required along with the vetch dessicant. In drier areas, dessication may have to take place 2 to 4 weeks prior to spring planting for soil moisture recharging; but if moisture is not limiting corn may be planted into the growing vetch and dessication with 2,4-D delayed until the corn has emerged. This gives the vetch an extra period to fix N and allow some reseeding if desired.

It is not uncommon for vetch DM yields to exceed 4 metric tons/ha with a N concentration of 3.5 to 4.0%. This is equivalent to about 200 kg N/ha produced. As previously mentioned, only a portion of this quantity will be available to the following crop. Weeraratna's (1979) work with the mineralization of several tropical legumes under aerobic conditions indicated that ammonium-N production reached a maximum rate in the fourth week of decomposition and that nitrate-N levels increased continually throughout the 7-week study. This rate of mineralization is dependent on many factors such as legume C/N ratio, soil moisture, temperature, pH, soil N levels and populations of nitrifying organisms. Decomposition of the mulch in a NT system may progress more slowly than when the residue is incorporated due to less contact with soil bacteria and less humid conditions. This surface decomposition may lead to higher volatilization losses of N but it also releases the N more slowly and thus less is lost by leaching. Whiteman (1980), working with tropical Desmodium, reported that about 75% of the total N fixed by the legume was in the topgrowth while the roots and nodules contained 10-15% each.

Recent studies with vetch have been promising. Gallaher (1982) indicated that hairy vetch provided almost all the N required by grain sorghum and corn. Grain yields of both crops were significantly greater when NT into hairy vetch rather than when CT is used.

Hairy vetch as a winter green manure crop is currently under investigation in Alabama, Florida, Georgia, North and South Carolina, Kentucky and Tennessee. Corn yields following hairy vetch in Kentucky were higher than those following crimson clover and big flower vetch (Vicia grandiflora), partly due to the greater dry matter production and higher leaf-N concentration of the vetch. Preliminary studies in the other states indicate that hairy vetch will probably supply about 100 kg N/ha/year, depending on the total DM production (Hargrove and Thomas, 1981). Non-irrigated hairy vetch in Texas produced 2310 kg DM/ha with 3.8% N for a total N production of 100 kg/ha, not enough to cover legume establishment costs (Reynolds et al., 1958).

Crimson Clover

Seeding winter legumes is often as expensive as the commercial N they replace. If many legumes are allowed to mature seed prior to the planting of the spring crop, the cost of reseeding in the fall may be eliminated. Crimson clover is currently one of the few legumes that matures early enough to allow timely spring seeding for some crops. Due to relatively early planting dates required for optimum corn yields, crimson clover may be the best alternative if corn is to follow a winter legume. When considering a legume reseeding program, however, even crimson clover matures too late for both seed production and optimum corn planting. Reseeding systems will perhaps work best with grain sorghum (Sorghum bicolor L. Moench), for which optimum planting dates run from mid-May to mid-June throughout much of the Southeast.

Touchton et al. (1982) tested reseeded crimson clover as N source for no-tillage sorghum production. Nitrogen produced by the clover (approximately 100 kg/ha/year) was sufficient for maximum sorghum production. When the clover residue was removed, sorghum yields still did not respond to applied fertilizer N; however the authors speculated that a factor other than N was limiting yield.

By allowing crimson clover to mature and then cut it for hay, some reseeding by shattering is accomplished and a cash crop is harvested. The hay would be of poorer quality, however, than if it was cut pre-bloom and the regrowth allowed to reseed. Although removing the topgrowth for hay removes most of the N, the grower still retains the reduced erosion and soil moisture conservation benefits of the winter legume as well as an additional 10 to 50 kg N/ha that remain in the roots and nodules. This system might be ideal when the spring crop is to be another legume as excess soil N may inhibit nodulation and DM yields of these crops.

Lupine

The cultivation of lupine (Lupinus spp.) is relatively recent in the southeastern US. Alkaloid-free (sweet) lupine was developed in Germany early in the 1950's (Gladstone, 1978). Lupine angustifolius varieties are grown mainly for seed production while L. luteus varieties are utilized mainly for forage and green manure. At present Australia grows lupine on a large scale as a green manure crop and to a lesser extent the USSR does also. This legume is well adapted to sandy, infertile soils and will produce large quantities of N under adequate growing conditions. Thompson (1959) reported 1700 kg/ha grain yield increase in corn following lupine as opposed to continuous corn. The 10-year study also indicated that lupine and peanut do not go well together in rotation because of several common diseases. Lupine will mature later than crimson clover but will probably produce more N/ha if moisture is adequate. One disadvantage of lupine is that is will not establish well if not seeded with a planter, so broadcast overseeding options such as those with vetch or clover are not possible.

Other Legumes

Austrian winter pea was a very popular winter legume during the early part of the century but for some reason is not widely used today. Scott (1929) reported it was the best winter legume available in Florida. In North Carolina, Blair (1930) reported that Austrian winter pea was ready to turn under before either vetch or crimson clover. This legume, like lupine, is large-seeded and will not establish well by broadcasting.

A recent Florida study (Soffes, 1981) with warm season legumes indicated that crotalaria, hairy indigo (*Indigofera hirsuta* L.), Norman pigeon pea (*Cajanus cajan* L.) and velvetbean fixed 200, 300, 300 and 135 kg/ha, respectively. Some of the most promising cool-season legumes that are well-adapted to northern U.S. areas, namely alfalfa (*Medicago sativa* L.) and sweet clover (*Melilotus alba* L.), may have some potential in the South but only after an intensive breeding program better adapts them to pest and soil conditions.

To date most green manuring work has been conducted with winter legumes providing the soil cover and N source for a summer cash crop. Using tropical legumes as an N source for winter cash crops is not feasible in most states although Florida is conducting some work along these lines. This "reverse" system has several disadvantages, however. Weed control in the summer legume is even more difficult than in winter legumes. The mineralization of N from the decomposing legume is also slowed considerably as temperatures drop in the fall.

In addition, most of the warm season legumes have not been refined as much as the temperate ones and much less is known about them. R.K. Reddi (personal communication) estimates that a smaller percentage of N fixed by summer legumes is utilized by the winter crop than in the reverse situation. In his Florida study, rye and wheat still responded to small increments of N even when following warm season legumes. In another Florida study (Smith, 1981) Norman pigeon pea, velvetbean, and crotalaria were intercropped with corn. Only a small percentage of the total N fixed by these legumes was transferred to the companion corn crop.

Summary

Escalating N fertilizer prices and increased awareness of the hazards of soil erosion have renewed interest in green manuring winter legumes. Properties of an "ideal" legume include (a) capability of fixing at least 200 kg N/ha; (b) ease of establishment (broadcast seeding); (c) fast winter growth and early seed set; and (d) suitability for NT planting of a spring crop into the residue.

So far hairy vetch and crimson clover have shown the most promise but there are still problems with both. These two legumes and several others seem to be capable of supplying the following crop with 60 to 120 kg N/ha, which is often enough for good yields. Neither one grows quickly enough to fix large quantities of N and still be mature in time for optimum corn planting; however, that may not be critical as the economics of corn production in the Southeast has led to drastic reductions in that crop's acreage.

Concurrent with the development of these winter legumes is the NT technology that makes the system even more attractive. Time is not wasted incorporating the legume so it may be allowed to grow as long as soil moisture or calendar date permits. The decaying mulch will slowly release N and the topsoil is protected by the mulch.

Aside from the improvements made by NT or low-energy technology, green manuring is not much different than it was a century ago. The same legumes are still being used and their yields have not been significantly increased. It is not that so much greater N production that is needed, though, as it is a short-season legume that produces DM levels of today's current selections in 2 or 3 weeks less time. Breeding programs could select for quick-growing annuals that are prolific seed producers or possibly a cool season annual that goes dormant in the summer. In any case, it is unlikely that the current popularity of multicropping with legumes will fade much so the renewed efforts by breeders, production agronomists, and pest managers will probably be rewarded by a whole new farming concept in the next decade or two.

Multicropping

Multicropping, the growing of more than one crop per year on the same area of land, is one promising alternative in increasing food production. When one of the crops in rotation is a legume, there may be an added benefit of N added to the system. When reduced tillage practices are introduced to multicropping systems there are also the additional benefits of reduced energy inputs and soil erosion, as well as increased water retention and utilization below the mulch. The possible interactions among climate, crop, and soil in such a system are immense and not well understood. This study will concentrate on three particular double-cropping systems and has been designed to investigate not only the overall agricultural dilemma as stated previously but also to devise a particular system and technology package that could be modified to be applicable to a subsistence farmer in the tropics or a large farmer in the southeastern US.

Multicropping is often divided into two major categories, intercropping and sucession cropping (Andrews and Kansam, 1976). Intercropping, in which two or more crops are grown simultaneously on the same field, is practiced mainly on small farms in the tropics. Intercropping has many sound advantages for its users including reduced risk of crop failure, diversification of diet, higher land equivalent ratios (LER), more efficient use of water and nutrients in the soil profile, and often reduced pressures from pests. Intercropping systems are not well adapted to mechanization, however, and tend to be highly labor intensive. Nutrient cycling within such systems is complex and often a particular system works well only within a small geographic area.

In contrast, succession cropping involves the production of two or more crops in succession on the same piece of land in 1 year. Because this form of multicropping lends itself well to mechanization and can better utilize research conducted on its component crops, succession cropping has gained rapidly in popularity in the U.S.

Extensive reviews and examples of these and other multicropping systems are available in the literature (Mateo, 1979) and several others will be examined in detail in a subsequent section. Of particular interest to this study are those systems adaptable to the tropics and subtropics, especially in the southeastern U.S. Perhaps the two most popular multicropping systems in this area are small grain/soybean and corn/soybean. Similar grass/broadleaf double-cropping systems are found world-wide, and for a variety of reasons. These systems often have the advantages of breaking up the life cycles of pests such as weeds, insects and diseases. Because of the difference in rooting patterns and nutrient requirements of grasses and legumes, more efficient use of soil moisture and nutrients often accompanies such a system. Furthermore, it has been noted that keeping a growing crop on the land for as much of the year as possible has contributed to a tighter nutrient cycle -- often only the grass crop need be fertilized while the succeeding legume uses residual nutrients in addition to providing most of its own N (Post, 1983).

There is little doubt that a shift to multicropping systems will entail higher management levels. Planting dates, pesticide and fertilizer carryover, and water and labor requirements all must be refined by the grower for his particular system. By recognizing growers' needs, constraints and market demands, the scientific community can greatly aid in the ultimate acceptance and success of systems adapted to each area of study.

Because an almost limitless number of multicropping systems may be possible for many soil types, the science of fertilizing multicropped soils is not well advanced. Bradfield (1970) studied several multicropping systems and determined fertilizer requirements by summing the requirements of each crop. This practice undoubtedly ensures adequate fertility for the system but in most cases would not be economically feasible for small farmers in the tropics and subtropics. A better understanding of nutrient cycling within the system would allow part of the nutrient requirement of one crop to be supplied by the decomposition of prior crops.

Nye and Greenland (1960), in discussing nutrient cycling in shifting cultivation, describe the tropical rain forests as existing in a more or less "closed system." That is, since few nutrient losses occur through leaching or runoff and no crop is removed, the nutrients within a given area cycle fairly efficiently and are stored mainly in the phytomass and top horizons of the soil. To approximate this system and keep fertilizer inputs to a minimum should be the primary goal in soil fertility management for multicropping/no-tillage systems. To reduce nutrient loss to that removed by harvest while minimizing leaching and erosional losses requires not only continuous cropping but careful management of tillage and crop sequence.

The initial step in establishing a fertility program for a particular system is to characterize the soil, physically and chemically, and gather information on the nutrient requirements of each crop to be included within the system. Subsequent study of management practices to "close" the system by avoiding nutrient losses and methods and timing of fertilizer inputs will go a long way in developing a suitable program for that system.

Double-cropping has been practiced in northern Florida for many years. A partial list of general system options is listed below (Lewis and Phillips, 1976).

Winter Crop	Summer Crop
Small grain for	corn (grain or silage)
grain	soybean
silage	sorghum (grain or silage)
hay	sorghum-sudangrass
grazing	millet
green chop	

A growing season in excess of 235 days is conducive to a multitude of systems even if a winter crop is not grown. Rainfall deficient periods in May and October may limit certain planting dates and choice of crops (Butson and Prine, 1968). Prine et al. (1978) reported early maturing corn and sunflower (*Helianthus annuus*) for early spring planting are desirable as they may be harvested early enough to allow a second crop to mature before fall frost. They found short-season soybean, pearlmillet (*Pennisetum americanum* L.), and several forage crops to be viable second crops. Late planted (August 14) forage sorghum averaged 7110 kg forage DM/ha in that study.

Some detailed studies of fertility requirement and production practices for several multicropping systems in Florida are available. A partial list of these systems includes the following: rye/soybean (Gallaher and Westberry, 1979), cabbage (*Brassica oleraceae* L.)/corn (Mateo, 1979), corn/soybean (Gallaher et al., 1979) and potato (*Solanum tuberosum* L.)/grain sorghum (Mateo 1979).

Effects of No-Tillage Management on Soil Properties

No-tillage and minimum tillage (MT) agriculture have gained rapidly in popularity during the past decade, especially in the southeastern United States. Compared to conventional tillage (CT) systems, NT and MT can offer several advantages including: increased soil moisture availability (Gallaher, 1977), reduced soil erosion loss (Langdale and Leonard., 1982), fewer planting delays and fuel and total energy savings (Robertson and Prine, 1976). In addition, NT practices allow growers to utilize crop residues and mulches more effectively for soil improvement and crop protection. Probably the major contributing factors to yield response from the use of mulch are increased water infiltration and reduced losses from water runoff (Langdale and Leonard, 1982). By covering the exposed soil surface, mulches reduce water loss from evaporation as well as reducing erosional losses due to wind and water. There is also abundant literature detailing the advantages of mulch as a soil temperature moderator through its insulating effects (Khera et al., 1976). Mulches may also be used as a soil amendment by increasing water holding capacity and providing new cation exchange sites for improved nutrient retention.

Of particular interest to this study is the effect NT may have on soil chemical properties. No-tillage management encourages residue build-up on the soil surface due to reduced exposure to soil microorganisms. This results in a slower decomposition rate (Smith, 1979) compared to CT soils (Sommers and Biederbeck, 1973). Much of the N from surface residues may be lost through leaching and denitrification under NT (Smith et al., 1980). In many cases, N in the soil surface tends to build up in the surface of NT soils. The rate of mineralization and mechanisms of N loss under NT conditions are not well documented. Despite increased microbial activity in the top 10 cm of a NT soil (Doran, 1979) and greater earthworm activity in NT soils (Lal, 1979), NT systems may initially require increased applications of fertilizer N to compensate for the N immobilized by these soil organisms. Lal (1976) also credits reduced losses of soil N to less erosion under NT management and the gradual accumulation of OM in the soil surface.

The build-up of soil OM is a slow process, however, and is affected by many factors. The sandy, well-aerated soils of the Southeast encourage rapid mineralization (Abd-Malek, 1976). Soil OM nearly doubled (2.4 to 4.2%) after 20 years for a grass/legume pasture on a sandy Florida Spodosol (Blue, 1979). These conditions would be much more favorable to OM build-up than a NT multicropping system, however, and one would not typically expect to see this rate of increase.

The literature does support the conclusion that soil OM and N will gradually accumulate under strict NT management. It is also apparent that mineralization proceeds more slowly in NT soils so that organic N will be released more slowly than under CT conditions, at least initially. Eventually an equilibrium should be reached and the long-term consequence of NT management may be to lessen leaching losses of mineralized N and to effectively tighten the N cycle, especially in multicropping systems.

Several studies have focused on N behavior in NT corn production. Bandel et al. (1975) observed that with suboptimal corn production, however, N uptake was the same for both tillage regimes and neither system had higher residual soil N at corn harvest. This observation may help support the belief that although NT may slowly increase soil N through OM build-up, the "use it or lose it" law still applies and unless another crop is actively growing as organic N is mineralized, it will still exit the system. Legg (1979) found that soil N tended to decrease with increasing N rates but was unaffected by tillage. In both years of this study uptake and recovery of fertilizer N was higher under NT than under CT.

Due to its immobility, the fate of P in NT systems was of major concern to early researchers. That P tends to accumulate in the surface of NT soils is well recognized (Moschler et al., 1975 and Lal, 1976). Accumulation of OM and the immobility of applied P probably both contribute to this result (Phillips and Young, 1973). Several studies have examined the fate of surface applied P in NT corn. In a Virginia study (Singh et al., 1966), corn leaf tissue had equal or greater amounts of P where superphosphate was incorporated. A later study in Ohio showed similar results (Triplett and Van Doren, 1969).

Surface soil K levels may also initially increase under NT management. Rhue and Sartain (1978) observed that K and Mg were most likely to be deficient in Florida soils. If, then, Florida soils are inherently low in soil K and mineralization rates are slower in NT soils, one might expect K nutrition of Florida NT crops to be of major consequence. In Wisconsin, Schulte (1979) recommended that K levels should be built up throughout the plow layer before a NT program is initiated and occasional tillage to enhance mineralization may also be necessary.

The fate of Ca and Mg in NT systems is not well documented but a few studies on soil acidity under NT management have contributed some information on the subject. The mixing of the surface soil in CT often results in a fairly uniform pH in the plow layer. In NT soils, however, a stratification occurs with upper layers of the soil becoming fairly acidic while lower layers maintain stability. Thomas (1975) reported that the increased OM in the upper layers of a NT soil tends to neutralize Al toxicity and Blevins et al. (1977) attributed this phenomenon to high NT corn yields on a soil with a surface pH of 4.0. The authors also reported higher levels of soil Ca in CT plots than in NT plots. In contrast, Juo and Lal (1979) found that both Ca and Mg were increased by long-term NT management, probably due to higher OM levels. Cropping system may also influence Ca and Mg cycling in NT systems (Post, 1983). The important interaction of K, Ca, and Mg is dealt with in a subsequent section.

The effect of NT on micronutrient availability is not well documented. Phillips and Young (1973) reported no significant differences for several micronutrients in a study comparing NT and CT management. In another study Ca, Mg, P, Mn, and Zn were higher in the soil surface 7.5 cm with NT management as opposed to CT (Hargrove et al., 1982).

Mineral Composition of Corn and Sorghum

Corn and grain sorghum production may be greatly enhanced by proper fertilization. As fertilizer efficiency is highly interactive with many soil properties and climatic factors, plant analysis has been used as a measurement of the soil-plant nutrient environment. Since nutrient availability as measured by soil testing may or may not be highly correlated to final crop yields, plant analysis can be used effectively in conjunction with soil tests to examine both critical levels of nutrients needed by the crop and the ability of the soil to supply these amounts. Both of these analyses are necessary to determine nutrient cycling in multicropping systems and to refine the fertilizer requirements of a particular system.

Abundant literature exists concerning plant analysis data for corn although few data are available for grain sorghum. Because of this imbalance and the observations of early researchers that the two crops contain similar amounts of most elements, they have often been discussed together. Lockman (1972) and Bennett (1971), however, warn that although nutrient concentrations in the crops are similar, differences increase in later growth stages and corn data should not be used to evaluate grain sorghum.

Since nutrient elements are not evenly distributed throughout a plant and fluctuate widely during its growth, it is of great importance to standardize time of sampling and plant part to be sampled. It is generally recommended that, for diagnostic purposes, corn be sampled by collecting 12 to 25 ear leaf samples from tasseling to silk initiation, and grain sorghum be sampled by collecting 15 to 25 samples from the second leaf from the top of the plant at heading (Jones and Eck, 1973). Whole plant sampling at physiological maturity is not a good measure of nutrient sufficiency in a plant but may be used to determine total plant content to be used in nutrient cycling determinations.

Critical nutrient level (CNL) determinations have been the object of much controversy and may be defined in several ways (Tyner, 1946; and Ulrich, 1952) but is essentially the concentration of an element below which yields decrease or deficiency symptoms appear. Because of the numerous interactions among nutrient elements themselves (Peck et al., 1969) and other confounding influences such as soil types (Gallaher and Jellum, 1976) and cultivar differences (Lutz et al., 1972), CNL values must be used with care. Table 1.1 lists ranges of CNL's for corn and grain sorghum. Values are for ear leaf at silk for corn and 3rd leaf below head at bloom for grain sorghum.

Lockman (1972) further reported that N and P levels in leaf tissue were both well correlated with sorghum grain yield but that K levels were more irregular and not as well correlated. Zinc levels exhibited a curvilinear correlation with grain yield, the correlation becoming negative as yields increased above the 6280 kg/ha levels.

In corn, yields and nutrient concentrations in the leaf may be also highly correlated. Bennett et al. (1973) noted grain yield increases with increasing N and P levels in the ear leaf with the following relationship: $Y= -17.14 + 20.11N + 152.98P$ where $Y=$ yield, $N=$ percent N and $P=$ percent P in the leaf. This equation corresponds to a 128 kg/ha yield increase for each additional 0.1% N in the leaf and a 960 kg/ha increase for each 0.1% change in P. Their CNL for N in

Table 1.1. Critical values for corn sufficiency ranges for corn and sorghum.

Element	Critical values for corn Jones (1970) Ear leaf	Nutrient sufficiency ranges Lockman (1972) Corn, ear leaf	Nutrient sufficiency ranges Lockman (1972) Sorghum 3rd leaf	Corn grain Jones (1970) at maturity	Sorghum grain at maturity*
		%			
N	3.00	2.76-3.50	3.3-4.0	1.0-2.5	2.02
P	0.25	0.25-0.40	0.20-0.35	0.2-0.06	0.42
K	1.90	1.71-2.50	1.4-1.7	0.2-0.4	0.37
Ca	0.40	0.21-1.00	0.30-0.60	0.01-0.02	0.012
Mg	0.25	0.21-0.60	0.2-0.5	0.09-0.20	0.17
		ppm			
Mn	15	20-150	8-190	5-15	23
Fe	15	21-250	65-100	30-50	45
Zn	15	20-70	15-30	-	200
B	15	20-70	15-30	1-10	-
Cu	5	6-20	2-7	1-5	13
Al	-	200	0-220	-	-

* Determined by Agronomy Research Support Laboratory and Analytical Research Laboratory of the Soil Science Department, University of Florida.

this series of experiments ranged from 2.8% to 3.0%. When the authors compared the value of leaf vs. grain analysis in assessing the N status of plants, they found that N in the grain and yield were poorly correlated but that leaf N and yield were usually well correlated.

Little information comparing plant analysis under CT and NT exists. Estes (1972) did make this comparison in corn in a New Hampshire study. A summary of his data is presented in Table 1.2.

Only K tissue levels were higher under NT while the significantly lower levels of Ca and Mg are noteworthy, perhaps substantiating the argument for more frequent liming under no-tillage conditions (Shear and Moschler 1969). However, another explanation for the increased K uptake under NT conditions is that higher soil moisture levels may cause more K to be present in the soil solution, thus inhibiting Ca and Mg uptake. The K/(Ca + Mg) balance is well documented (Gallaher et al., 1975a) and may be the primary reason that increasing K levels in plant tissue are not well correlated with final yields.

Even with the increased interest in nutrient cycling today, determining nutrient sufficiency levels through plant analysis and soil testing is as much an art as a science. Tissue testing must be an integral part of any nutrient cycling study in order to monitor total uptake by the crop, timing of uptake, and total contents removed by harvest and returned to the system via the residue.

Materials and Methods

The research was conducted in 1982 and 1983 at the Green Acres Agronomy Farm, Gainesville, Florida. The soil was an Arredondo fine sand, a member of the loamy silicious hyperthermic family of the Grossarenic Paleudults. The soil is fairly well-drained but is slightly compacted at 20 to 30 cm and is high in residual phosphates.

Table 1.2. Relationship between critical composition (literature) of 7 elements in maize under no-tillage and conventional tillage.

Nutrient	Critical composition	Experimental values, mean of 5 replications: No-till	Experimental values, mean of 5 replications: Conventional	% change, relative conventional tillage
Phosphorus, %	0.25	0.34	0.34	0.0%
Potassium, %	1.90	1.66	1.53	+8.5%
Calcium, %	0.40	0.77	0.85	-9.4%
Magnesium, %	0.25	0.50	0.59	-15.2%
Zinc, ppm	15	26	29	-10.3%
Iron, ppm	25	154	161	- 4.3%
Manganese, ppm	15	77	84	- 8.3%

Denotes significant differences between cultural method (p= .05). employed in assessing nutrient status of maize as presented by Melsted (1969).

Experiments one and two utilized a randomized complete split plot design with five replications. Experiment three was conducted only in 1983 and used the same design with four replications. Treatments for experiments one and two are listed below. All treatments were imposed solely on the grain sorghum crop.

Main Treatment	Subtreatments
No-tillage,legume removed	0 kg N/ha
No-tillage, legume left	25 kg N/ha
Conventional tillage, legume removed	50 kg N/ha
Conventional tillage, legume left	75 kg N/ha
	100 Kg N/ha
	150 Kg N/ha
	200 Kg N/ha

Experiment One

The cropping system was fall-planted crimson clover followed by grain sorghum. The soil was tilled to a depth of 15 cm with a rototiller before legume establishment. Crimson clover (cultivar 'Dixie') was planted at 25 kg seed/ha in early November. Clover seeds were inoculated and planted in 25 cm rows with a Tye drill. Potassium, Mg, and S were applied at planting according to soil test recommendations. No herbicides were employed on the clover; however, in 1983, 2.2 kg a.i. glyphosate (N-phosphoromethylglycine)/ha was applied preplant when rain delayed planting after tillage was completed. In the spring, clover was sampled for DM yield and nutrient concentration, then mowed to a height of 7 cm and removed or left standing as the treatment dictated. The clover mulch was killed (on NT plots) with an application of paraquat and 2, 4-D immediately following sorghum planting. May-planted grain sorghum (variety 'GK 802G') was seeded at 9 kg/ha with a 25 cm spacing with a Tye drill in 1982. A Brown-Hardin Super Seeder with 76 cm row spacings was used in 1983 to facilitate weed control by allowing a post-directed herbicide application. Nitrogen was applied as NH_4NO_3 at seven rates, 0, 25, 50, 75, 100, 150, and 200 kg N/ha in split applications, the first immediately after planting and the second 4 weeks later.

Clover whole-plant samples were taken just prior to sorghum planting. Grain sorghum was sampled at early heading (10 to 15 samples consisting of 3rd leaf from the head) and again at maturity (whole-plant). All plant samples were dried at 70 C for a minimum of 48 hours prior to weighing, then chopped in a mulching machine (Amerind MacKissic) and ground in a Wiley mill to pass a 1-mm stainless steel screen.

Nitrogen concentration was determined by a microKjeldahl procedure (Bremmer, 1965) as modified by Gallaher et al. (1976). A 100 mg sample of ground plant tissue was placed into a 75 mL digestion tube along with two boiling chips, 3.2g of catalyst (90% anhydrous K_2SO_4. 10% anhydrous $CuSO_4$) and 10 mL concentrated H_2SO_4. Samples were digested for three hours at 380 C (Gallaher et al., 1975b). After they were diluted to 75 mL volume they were analyzed colorimetrically using an autoanalyzer.

Phosphorus, K, Ca, Mg, Cu, Zn, Mn, and Fe concentrations in plant tissue were determined by weighing 1.0 g of ground plant material into a 50-mL. pyrex beaker and ashing at 480 C for a minimum of 6 hours. After cooling, 2 mL of concentrated HCl were added to the ash and the mixture was slowly heated until dry. An additional 2 mL of concentrated HCl and approximately 15 mL of water were added to the beakers after cooling. The mixture was covered with a watch glass and digested for 30 minutes on low heat. Solutions were diluted to 100 mL and stored in plastic vials. Phosphorus was determined colorimetrically, K by flame emission spectrophotometry, and the others by atomic absorption spectrophotometry.

Soils were sampled three times during each cropping year, once prior to legume establishment, once prior to sorghum planting, and again at sorghum harvest. Soil was sampled to a depth of 20 cm in a single increment except the last sampling date in 1983, when an additional 20 to 40 cm increment was taken.

All soil samples were air-dried and sieved to pass a 2-mm screen. Total soil N was determined by the modified microKjeldahl procedure described above, except that a 2 g sample was used. Extracts for mineral analysis were obtained by mixing 5 g soil with 20 ml 0.05 M HCl + 0.025 M (1/2 H_2SO_4) and shaking 5 minutes before filtration.

Plant content was determined by multiplying concentration of the plant element by total plant dry matter (DM). Soil content was determined by multiplying concentration in the soil by soil weight in the plow layer of a hectare. A summary of the herbicides, insecticides and non-treatment fertilizers for all three experiments appears in Table 1.3.

Experiment Two

The second experiment was identical to experiment one except that the system investigated was lupine (cultivar 'Tift blue')/grain sorghum. As the two experiments were side by side in the field, field operations were scheduled for both experiments at the same time. All sampling, harvest and pesticide applications were usually conducted on the same day for both experiments. The one exception was that since the lupine had no regrowth after mowing, it was not sprayed with paraquat prior to sorghum planting as was the crimson clover. Laboratory analysis was as described above.

Experiment Three

The third experiment examined the same parameters as previously described, but in a crimson clover/corn system. Experiment three was conducted for 1 year only, fall 1982 until summer 1983. Crimson clover (*Trifolium incarnatum* L.) was established on tilled ground in November and harvested in early March. Corn (variety Funks 'G4507A') was planted the day after clover harvest at 84,000 plants/ha in 76 cm rows. A randomized complete split plot design with four replications was used. Main plots consisted of the same four

Table 1.3. Herbicides, pesticides, and non-treatment fertilizers used in legume/sorghum and corn systems.

Crop	Input	Method of application	Quantity used per ha
Lupine, crimson clover(Exp 1,2,3)	calcium magnesium sulfate	broadcast preplant	188 kg of 22-11-22
Grain sorghum (Exp 1,2)	paraquat(1)	broadcast preplant	0.28 kg a.i.
	2, 4-D(2)	broadcast preplant	0.605 kg a.i.
	paraquat	post directed	0.43 kg a.i.
corn (Exp 3)	paraquat	broadcast preplant	0.28 kg a.i.
	atrazine(3)	broadcast preplant	2.24 kg a.i.
	carbofuran(4)	broadcast preplant	2.24 kg a.i.
	paraquat	post directed	0.28 kg a.i.

(1) 1,1', dimethyl, 4,4' bipyridinium ion present as the dichloride salt/ha plus 236 mL Ortho X77 surfactant/378 L water.

(2) 2,4-dichlorophenoxy aceticacid/ha

(3) 2-Chloro-4-ethylamine-6-isopropylamine-s-triazine

(4) 2,3-Dihydro-2,2-dimethly-7-benzofuramyl-methylcarbamate

tillage-mowing treatments as described above; however, subtreatments (N levels) were restricted to four levels; 0, 25, 50, and 100 kg N/ha and were not split applied. Plant sampling included whole plant for clover and ear leaf at tasseling, whole plant and cob subsamples at harvest for corn. Pesticide and non-treatment fertilizers are detailed in Table 3. Laboratory analyses for tissue and soil samples were identical to those described for Experiment One.

Experiment Four

A 2-year study investigating management of several winter crops grown in succession with grain sorghum that was completed in 1979 was analyzed for inclusion in this paper. A detailed description of this study is included in Chapter 6.

Statistical Analysis

The statistical analysis included analysis of variance (ANOVA) for all responses and regression analysis where appropriate. Although data from individual years were analyzed separately, most statistical results reported here are for 2-year averages. Where ANOVA indicated differences (probability of $F<.05$) Duncan's Multiple Range Test (DMRT) to compare tillage means was employed. Summary tables for ANOVA and DMRT results appear in the appendix. In the cases where there was response to N fertilization rate, appropriate regression analysis was conducted. As no response exhibited trends greater than a cubic nature, LOF sums of squares for the fourth through seventh order were ignored and incorporated into the error term. Regression terms were incorporated into the model if judged significant at the 0.10 level by the F-test or if a higher order term in the same variable was judged significant.

The ANOVA, DMRT and regression analyses for all of experiments 1 and 2 and parts of experiment three were preformed at the Northeast Regional Data Center (University of Florida, Gainesville FL) using the General Linear Model

(GLM) procedure of the Statistical Analysis System (SAS). Data filing, transformations, and DMRT for experiment three were preformed on a Tandy Radio Shack TRS-80 Model III (48K RAM) microcomputer.

CHAPTER 2.
NITROGEN RELATIONS IN A WINTER LEGUME/GRAIN SORGHUM CROPPING SYSTEM

Introduction

Legumes have been utilized as an organic mulch and N source in cropping systems for thousands of years (Davis et al., 1940). Frequent mention of winter-cropping legumes, particularly hairy vetch (*Vicia villosa* Roth) and crimson clover (*Trifolium incarnatum* L.), started to appear in the literature in the U.S. in the 1890's, and by 1920 almost every agricultural extension office in the southeastern U.S. was recommending winter legumes for erosion control and soil building. The practice declined drastically in the post World-War II era with the advent of inexpensive N fertilizers; however, the changes in economics of inorganic N useage and growing concern over soil erosion losses have sparked a comeback for green-mulching winter legumes in rotation with summer grains in the southeastern United States.

There are a number of recent studies examining the practicality of using soil-incorporated legumes as a N source for a following grain crop. However, studies examining the use of legumes as a no-tillage (NT) mulch or directly comparing conventional-tillage (CT) and NT seedbed preparation following the legume are scarce.

Leaving clover (*Trifolium* sp.) on the surface for a year before incorporation did not affect N loss to leaching (Albrecht, 1936). Triplett et al. (1979) reported tillage was not necessary to release N contained in the legume crop. Efficient recovery of the mineralized N is likely dependent on soil moisture and other factors. Because there may be more moisture in the soil surface under NT conditions, inorganic N recovery can be greater under NT as compared to CT in dry years (Moschler et al., 1975). Grain sorghum (Sorghum bicolor L. Moench) yield differences between NT and CT have been reported to be minimal with good management (Nelson et al., 1977 and Stanford et al., 1973).

The utilization of legumes as a N source for corn (Zea mays L.) and grain sorghum has received attention in recent years. Triplett et al. (1979) reported corn yield response to N-fertilizer in only 1 year in a 3-year alfalfa (Medicago sativa L.)/corn system. Others have reported maximum grain yields in corn or grain sorghum without additional N-fertilizer when following a legume (Mitchell and Teel, 1979 and Gallaher, 1982).

Critical leaf N values for grain sorghum are not well established, but Lockman (1972) stated that leaf N in grain sorghum at several vegetative stages was highly positively correlated with final grain yields. He further suggested that deficiency levels for the third leaf from the head at bloom stages were in the order of 2.5 to 3.2% N. Sorghum grain yields decreased as leaf N at full bloom dropped below 2% (Hipp and Gerard, 1971). Leaf N at this stage accounted for about 63% of the variation in grain yields.

Crimson clover has been investigated extensively as a green manure crop in the U.S., but lupine (Lupinus angustifolius L.) is popular in very few areas, most notably Australia. Dry matter accumulation and total N content may be higher than that of clover but susceptibility to frost, diseases, and nematodes have decreased its popularity in the S.E. United States. Thompson (1959) reported a 1680 kg grain/ha increase in corn yield following lupine but warned against following lupine with other legume crops because of possible common diseases. The large seed of lupine is difficult to establish by broadcast methods, thus the crop is not suitable for broadcast overseeding systems that hairy vetch and several clover species may fit.

Several disadvantages may be associated with green manure crops such as difficult and costly establishment, slow growth, and difficulty in establishing the following crop; possibly due to depleted soil moisture, or phytotoxicity (Beatty and Giddens, 1970). It may be possible to overcome the establishment problem by allowing crimson clover to reseed before NT grain sorghum planting (Touchton et al., 1982). The authors either removed or left clover tissue on the soil surface and applied six increments of inorganic N fertilizer. Removing the clover residue only reduced sorghum leaf N in 1 year of the 3-year study. Nitrogen from the clover was sufficient for maximum sorghum grain yield when clover residue was left, and was sufficient for maximum yields in 2 of the 3 years even when the residue was removed. Assuming total mineralization of the remaining clover residue after tops were removed, calculated available N was only 55 kg/ha. Since this was not enough to account for total N content of the sorghum crop, the authors speculated that N from the clover root system and other potentially mineralizable N in the soil contributed to the lack of response to N fertilizer in that year.

The objectives of this study were to examine the effects of utilizing a winter legume as a N source for spring-planted grain sorghum and the effects of removing the legume residue on the subsequent N utilization by sorghum. Levels of applied inorganic N beyond that supplied by the legume for maximum grain sorghum production were also investigated. Tillage effects of sorghum seedbed by NT and CT methods and their effects on the legume/grain sorghum system was also included in the study.

Materials and Methods

The experiment was conducted in 1982 and 1983 on an Arredondo fine sand, a member of the loamy silicious hyperthermic family of the Grossarenic

Paleudults. The soil is fairly well-drained but has a slightly compacted layer between 20 to 30 cm and is high in residual phosphates. Two separate experiments were conducted at the Gainesville, Florida, site. The first examined a crimson clover/grain sorghum system and the second, a blue lupine/grain sorghum system.

Both experiments utilized a randomized complete split plot design with five replications. Four main treatments were a combination of legume management plus tillage of the sorghum seedbed and included 1) no-tillage into legume for a mulch; 2) no-tillage into stubble of harvested legume; 3) conventional-tillage using a legume for green manure; and 4) conventional-tillage, after a legume was harvested. Subtreatments consisted of seven rates of N fertilizer; 0, 25, 50, 75, 100, 150, and 200 kg N/ha.

Clover/Sorghum System

The cropping system was fall-planted crimson clover followed by grain sorghum. The soil was tilled to a depth of 15 cm with a rototiller before legume establishment. The crimson clover (variety 'Dixie') was planted at 25 kg seed/ha in early November. Seeds were innoculated and planted in 25 cm rows with a Tye drill. Potassium, Mg, and S were applied at planting according to soil test recommendations. No herbicides were employed on the clover; however, in 1983, 2.2 kg a.i. glyphosate (N-phosphoromethylglycine)/ha was applied preplant when rain delayed planting after tillage was completed. In the spring, clover was sampled for DM yield and nutrient concentration, then mowed to a height of 7cm and removed or left standing as the treatment dictated. The clover mulch was killed (on NT plots) with an application of paraquat (1,1', dimethyl, 4,4' bipyridinium ion present as the dichloride salt plus 236 mL Ortho X77 surfactant/378 L water) and 2, 4-D (2,4-dichlorophenoxy acetic acid) immediately following sorghum planting. May-planted grain sorghum (variety 'GK 802G') was seeded at 9 kg/ha with a 25 cm spacing in a Tye drill in 1982. A Brown-Hardin super seeder with 76 cm row spacings was used in 1983 to facilitate weed control by allowing a post-directed herbicide application.

Nitrogen was applied as NH_4NO_3 at seven rates; 0, 25, 50, 75, 100, 150, and 200 kg N/ha in split applications, the first immediately after planting and the second 4 weeks later. A post-directed application of paraquat was applied to the sorghum at the rate of 0.28 kg a.i./ha 5 weeks after emergence.

Clover whole-plant samples were taken just prior to sorghum planting. Grain sorghum was sampled at early heading (10 to 15 samples consisting of 3rd leaf from the head) and again at maturity (whole-plant). All plant samples were dried at 70 C for a minimum of 48 hours prior to weighing, then chopped in a mulching machine (Amerind MacKissic) and ground in a Wiley mill to pass a 1-mm screen.

Nitrogen concentration was determined by a microKjeldahl procedure (Bremmer, 1965) as modified by Gallaher et al. (1976). A 100 mg sample of ground plant tissue was placed into a 75-mL digestion tube along with two boiling chips, 3.2 g of catalyst (90% anhydrous K_2SO_4: 10% anhydrous $CuSO_4$) and 10 mL concentrated H_2SO_4. Samples were digested for three hours at 380 C (Gallaher et al., 1975b). After they were diluted to 75 mL volume they were analyzed colorimetrically using an autoanalyzer.

Soils were sampled twice during each cropping year, once prior to legume establishment and again at sorghum harvest. Soil was sampled to a depth of 20 cm in a single increment except the last sampling date in 1983, when an additional 20-40cm increment was taken. All soil samples were air-dried and sieved to pass a 2-mm screen. Total soil N was determined by the modified microKjeldahl procedure described above, except that a 2 g sample was used. Extracts for mineral analysis were obtained by mixing 5 g soil with 20 ml 0.05 $\underline{M}$ HCl + 0.025 $\underline{M}$ (1/2 H_2SO_4) and shaking 5 minutes before filtration.

Plant content was determined by multiplying concentration of the plant element by total plant dry matter (DM). Soil content was determined by multiplying concentration in the soil by soil weight in the plow layer of a hectare.

Lupine/Sorghum System

The second experiment was identical to experiment one except that the system investigated was blue lupine (cultivar 'Tift blue')/grain sorghum. As the two experiments were side by side in the field, field operations were scheduled for both experiments simultaneously. All sampling, harvesting and pesticide applications were conducted at the same time for both experiments. The one exception was that since the lupine had no regrowth after mowing, it was not sprayed with paraquat prior to sorghum planting as was the crimson clover. Laboratory analyses were as described above.

Statistical analyses included analysis of variance for a split plot design. Significantly different tillage means were separated by the Duncan's Multiple Range Tests for significance at the 0.05 level of probability. Regression analysis was preformed on responses affected by N rate.

Results and Discussion

Crimson Clover/Grain Sorghum System

Dry matter, total N content, and leaf N concentration for crimson clover are given in Table 2.1. The 2-year average total N content of 144 kg N/ha was the result of a vigorous stand of clover that had not reached maturity at mulching, and thus retained a high leaf N concentration of 2.9%. As the clover was harvested close to ground level, little N was left on the soil surface in clover residue; however, other studies (Mitchell and Teel, 1977 and Whiteman, 1980) suggested that the clover root system may have contained another 10 to 30 kg N/ha. The present experiment was conducted on new ground each year so as not to allow residual N from the first year to interact with the response in the second year.

Nitrogen concentrations for grain sorghum in the third leaf from the head at early bloom are presented in Table 2.2. Values ranged from a low of 2.84% for the CT stubble to 3.11% for CT green manure. Both the NT mulch and CT green manure treatments had higher leaf N values than when clover residue was removed. Leaf N was lower for NT stubble than for the other treatments.

Grain sorghum dry matter and grain yields are given in Tables 2.3 and 2.4 respectively. Yields for both years were somewhat diminished by weed competition and moisture as irrigation was applied only during times of visible moisture stress to the sorghum crop (two times in 1982 and once in 1983). Sorghum grain yields were similar for both years of the study and were not affected by changing the row width in 1983. Sorghum DM yields were highest for the CT green manure treatment and did not differ for the other three. Maximum DM yields corresponded to leaf N values of approximately 2.9% and there was no response to applied N over the 50 kg N/ha rate. The CT stubble treatment had the lowest DM yield at the 0 kg N/ha rate.

Sorghum grain yield was maximum at 50 kg applied N/ha although N concentration increased rapidly from 0 to 25 kg applied N/ha and slowly thereafter. Maximum grain yields were obtained when leaf N was 2.95%, a value that corresponds to Lockman's (1972) CNL range of 2.5-3.0% but is higher than that proposed by Hipp and Gerard (1971). Overall grain yields were lower at the 150 and 200 kg applied N/ha rates, corresponding to leaf N values exceeding 3.3% (Fig. 2.1). Sorghum grain yields were highest when clover residue was left, regardless of tillage. As with DM production, grain yields for the stubble treatments were lower at low rates of applied N but were essentially equal at the 75 kg applied N rate (Fig. 2.2). When 100 kg N/ha or more were applied, grain yields diminished. Nitrogen concentration in the grain (Table 2.5) was also higher for the CT green manure treatment. Maximum grain yields corresponded to grain N levels of approximately 1.65% although the correlation was not high.

Whole-plant N levels at maturity ranged from 1.13% for the CT stubble treatment to 1.22% for CT green manure (Table 2.6). They were not as well correlated with grain or total DM yields as was leaf N at early bloom. Maximum grain yields were attained when total plant N levels were in the 1.10 to 1.25% range and were lower when plant N exceeded 1.30%.

Total N contents (kg residue x percent N in residue + kg grain x percent N in grain) for tillage and N rates are given in Table 1.7. As with grain yield, the CT green manure treatment had the highest total N content. Nitrogen content of the grain was higher in both the mulch and green manure treatments than where the clover was removed. Both of the NT treatments partitioned over 50% (avg. 52.5%) of their total N to the grain while the CT treatments were lower (avg. 46%). This may have been due to a greater water use efficiency or higher soil moisture contents under NT conditions.

Lupine/Grain Sorghum System

Lupine DM, leaf N concentration, and total N content are given in table 2.9. Lupine seedlings did not exhibit the vigorous fall growth common to other winter legumes such as hairy vetch or crimson clover, and weed competition during early growth was a problem both years. By February, however, a complete canopy was formed and by the April cutting the lupine crop was 1 m high with few visible weeds. Total N content in the harvested portion of the crop was 187 kg N/ha; enough for maximum grain yield of sorghum if the total amount was to mineralize during the sorghum growing season. Although lupine leaves were still succulent at harvest, stalks were approximately 1 cm thick and the plant was, in general, quite fibrous. Mowing the lupine helped to promote better soil-mulch contact so as to hasten N mineralization.

Nitrogen concentrations in the third leaf from flag at early bloom are given in Table 2.10. Only the CT green manure treatment had a leaf N higher than Lockman's (1972) critical level of 2.5% at the 0 kg N/ha rate; however, leaf N for all treatments was approaching 3.0% at the 25 kg applied N/ha rate. Maximum sorghum grain yields correlated with leaf N concentrations of 2.8 to 3.0%. Grain yields were maximum for CT green manure at the 25 kg N/ha rate and at the 50 kg N/ha for the other tillage treatments (Table 2.11). The trend was for the CT green manure treatment to have higher grain yields at the lower N rates as compared to the other treatments. This was probaly due to a faster rate of N mineralization caused by increased soil-lupine tissue contact.

Method of tillage did not affect sorghum whole plant DM yields (Table 2.12). Maximum DM yields occurred at the 100 kg N/ha rate. Nitrogen concentration of total plant DM at harvest increased with N rate and ranged from 1.04% at 0 kg N/ha to 1.36 at 200 kg N/ha (Table 2.13). Similarly, N concentration in the sorghum grain was not affected by tillage but did increase linearly with N rate and ranged from 1.25% at 0 kg N/ha to 1.82% at 200 kg N/ha.

Total whole plant N content was highest at the 50 to 75 kg N/ha rates as reductions in DM yields at the higher N rates were not offset by higher N concentration in the tissue (Table 2.14). Efficiency of applied N recovery is shown in Fig.2.3. Percent N recovery was calculated by subtracting N uptake of the check plot (0 kg N/ha rate) from total N uptake for a given N rate and dividing it by N uptake of the check plot. As tillage did not affect N content, values for each N rate are means of the four tillage treatments. Nearly 72% of the applied N was recovered in total DM at the 25 kg N/ha rate, decreasing linearly to a recovery rate of only 15% at the 200 kg N/ha rate. Applied N recovery in the sorghum grain ranged from 44% at the 25 kg N/ha rate to nearly 13% at the 200 kg N/ha rate. The trend was for CT treatments to have higher N recovery rates in the DM while NT treatments recovered more N in the grain, probably due to higher moisture levels in NT plots late in the season.

Total N content of sorghum was higher than the input of inorganic N for all treatments up to the 150 kg N/ha rate, indicating a substantial contribution of mineralized N. Soil test values for total N indicated that there was a positive N balance at the end of the season for most treatments up to the 50 kg N/ha rate (data not shown), a further indication that much of the mineralized N came from the legume. As inorganic N recovery was generally less than 30%, even at the lower N rates, it is possible that benefits other than additional N were derived from the legume.

Table 2.1. Dry matter yield, N concentration, and N content of crimson clover.

Year	DM	N concentration	N content
	--kg/ha--	------%--------	--kg/ha--
1982	4600	2.88	130
1983	5300	2.90	150
mean	5000	2.89	140

Table 2.2. Grain sorghum leaf N (3rd leaf from top at early heading) as affected by N fertilization and tillage when following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	% N							
NT mulch	2.58a	3.11a	3.00ab	2.92a	3.12a	3.41a	3.34ab	2.96
NT stubble	2.29ab	2.82b	2.78b	2.82a	3.01a	3.28a	3.42ab	2.85
CT grn manure	2.12b	2.97ab	3.27a	3.19a	3.20a	3.53a	3.53a	3.04
CT stubble	2.30ab	2.91b	3.03ab	3.29a	3.20a	3.29a	3.25b	2.92
Mean	2.32	2.95	3.02	3.06	3.13	3.38	3.39	2.94

* Tillage means within columns followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=2.72 +0.006x -0.00003x^2$	0.59
NT stubble	$y=2.42 +0.008x -0.00002x^2$	0.65
CT green manure	$y=2.37 +0.015x -0.00005x^2$	0.81
CT stubble	$y=2.32 +0.01x -0.00003x^2$	0.79

Table 2.3. Effects of N fertilization and tillage on grain sorghum dry matter when following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	DM (Mg/ha)							
NT mulch	9.30a	10.50a	9.70a	9.50b	10.20ab	8.60b	8.60ab	9.10
NT stubble	7.90ab	7.70b	8.50a	8.70b	8.00b	8.20b	8.20ab	8.00
CT grn manure	10.20a	10.20a	12.00a	12.80a	11.50a	14.60a	11.80a	11.40
CT stubble	6.70b	8.10b	8.90a	8.00b	8.00b	8.00b	7.50b	7.60
Mean	8.50	9.10	9.80	9.70	9.50	9.80	8.90	9.00

* Tillage means within the same column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Table 2.4. Sorghum grain yield as affected by N fertilization and tillage when following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	Grain (Mg/ha)							
NT mulch	4.20a	3.80a	4.20a	3.80b	4.00a	3.40a	3.40a	3.60
NT stubble	2.10c	1.90b	3.30ab	3.90b	3.80a	3.70a	3.60a	3.10
CT grn manure	3.10b	4.00a	4.50a	4.90a	3.60a	4.40a	3.90a	3.90
CT stubble	1.70c	2.80ab	2.80b	3.50b	3.20a	3.10a	3.30a	2.70
Mean	2.80	3.10	3.70	4.00	3.70	3.70	3.50	3.30

* Tillage means within the same column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	NS	
NT stubble	$y=1.87 +0.031x -0.0001x^{2}_{2}$	0.61
CT green manure	$y=3.46 +0.19x -0.00009x$	0.16
CT stubble	$y=1.93 +0.23x -0.00008x^2$	0.44

Table 2.5. Nitrogen concentration in grain of grain sorghum as affected by N fertilization and tillage when following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	% N							
NT mulch	1.23a	1.33a	1.46a	1.55a	1.57ab	1.80a	1.97a	1.54
NT stubble	1.28a	1.34a	1.38a	1.57a	1.58ab	1.85a	1.91a	1.53
CT grn manure	1.37a	1.55a	1.49a	1.64a	1.67a	1.93a	2.00a	1.62
CT stubble	1.36a	1.50a	1.38a	1.46a	1.51b	1.76a	1.73a	1.49
Mean	1.31	1.43	1.43	1.56	1.58	1.84	1.90	1.55

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=1.25 +0.004x$	0.72
NT stubble	$y=1.27 +0.003x$	0.74
CT green manure	$y=1.39 +0.003x$	0.80
CT stubble	$y=1.35 +0.002x$	0.48

Table 2.6. Grain sorghum tissue N (whole plant at maturity) as affected by N fertilization and tillage when following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	% N							
NT mulch	1.09a	1.06a	1.20a	1.23a	1.22a	1.34a	1.42ab	1.21
NT stubble	1.03a	1.15a	1.05a	1.23a	1.19a	1.25a	1.23b	1.16
CT grn manure	1.19a	1.14a	1.05a	1.24a	1.17a	1.40a	1.51a	1.22
CT stubble	1.06a	1.10a	1.10a	1.11a	1.17a	1.31a	1.34b	1.13
Mean	1.09	1.11	1.10	1.20	1.19	1.33	1.38	1.18

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=1.07 +0.002x$	0.53
NT stubble	$y=1.08 +0.001x$	0.39
CT green manure	$y=1.08 +0.002x$	0.57
CT stubble	$y=1.04 +0.0014x$	0.49

Table 2.7. Total N content of grain sorghum as affected by N fertilization and tillage when following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	DM (kg/ha)							
NT mulch	105ab	110ab	115ab	115b	125a	115b	115b	115
NT stubble	80b	90b	90b	110b	100b	100b	100b	95
CT grn manure	120a	120a	125a	160a	135a	205aa	180a	150
CT stubble	70b	90b	100ab	90b	95b	105b	100b	95
Mean	95	100	110	120	115	130	125	115

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=111 +0.05x$	0.52
NT stubble	$y=88 +0.09x$	0.72
CT green manure	$y=115 +0.39x$	0.84
CT stubble	$Y=82 +0.12x$	0.74

Table 2.8. Grain N content in grain sorghum as affected by N fertilization and tillage when following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	N content (kg/ha)							
NT mulch	50a	50ab	60ab	60ab	65a	60ab	70a	60
NT stubble	30b	30c	45bc	60ab	60a	70ab	70a	50
CT grn manure	40ab	65a	70a	80a	60a	80a	80a	65
CT stubble	25b	40bc	40c	50b	50a	55b	55a	45
Mean	35	45	55	60	55	65	70	55

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=52.7 +0.075x$	0.74
NT stubble	$y=31.0 +0.23x$	0.79
CT green manure	$y=55.0 +0.13x$	0.51
CT stubble	$y=32.7 +0.14x$	0.74

Table 2.9. Dry matter, N concentration, and N content of lupine.

Year	DM	N concentration	N content
	--kg/ha--	------%--------	--kg/ha--
1982	7300	2.48	180
1983	8000	2.44	195
mean	7700	2.46	190

Table 2.10. Grain sorghum leaf N (3rd leaf from top at early heading) as affected by N-fertilization and tillage when following lupine.

	N rate (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	% N							
NT mulch	2.47	3.10	3.12	3.24	3.08	3.08	3.43	2.97a
NT stubble	2.09	2.84	2.81	3.20	2.86	3.23	3.25	2.82a
CT mulch	2.69	2.98	2.98	3.13	3.04	3.42	3.37	3.00a
CT stubble	2.30	2.91	3.03	3.29	3.20	3.29	3.25	2.92a
Mean	2.39	2.96	2.99	3.22	3.05	3.26	3.33	2.93

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Overall regression equation: $y=2.44 +0.02x -0.0001x^2$ $R^2=0.66$

Table 2.11. Sorghum grain yield as affected by N fertilization and tillage when following lupine.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	Grain (kg/ha)							
NT mulch	1460	1970	3140	3190	3240	2760	3610	2630a
NT stubble	1850	1910	2570	2590	2420	2250	2300	2250a
CT grn manure	2290	3230	2830	3060	2740	2770	3050	2730a
CT stubble	1970	2330	3220	3160	2620	3050	2680	2590a
Mean	1890	2360	2940	3000	2750	2710	2910	2550

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Overall regression equation: $y=1850 +33.6x -0.33x +0.0009x^2$ $R^2=0.29$

Table 2.12. Grain sorghum DM yield as affected by N fertilization and tillage when following lupine.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	DM (Mg/ha)							
NT mulch	6.20	7.20	8.60	8.60	9.40	9.00	8.50	7.90a
NT stubble	6.20	6.50	7.40	7.40	8.20	7.50	6.20	6.90a
CT grn manure	6.20	8.00	8.50	8.10	8.20	7.30	7.00	7.30a
CT stubble	7.10	7.80	9.50	8.90	10.10	8.30	6.80	8.00a
Mean	6.40	7.40	8.50	8.20	9.00	8.10	7.10	7.50

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Overall regression equation: $y=6.40 +0.028x -0.00003x^2$ $R^2=0.36$

Table 2.13. Grain sorghum tissue N (whole plant at maturity) as affected by N fertilization and tillage when following lupine.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	% N							
NT mulch	1.08	1.26	1.26	1.18	1.10	1.34	1.29	1.19a
NT stubble	0.98	1.12	1.14	1.28	1.21	1.22	1.33	1.16a
CT grn manure	1.09	1.10	1.21	1.22	1.12	1.26	1.46	1.20a
CT stubble	1.05	1.18	1.16	1.41	1.19	1.32	1.39	1.21a
Mean	1.05	1.17	1.19	1.27	1.16	1.29	1.37	1.19

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Overall regression equation: $y=1.10 +0.001x$ $R^2=0.49$

Table 2.14. Grain N content in grain sorghum as affected by N fertilization and tillage when following lupine.

	N applied (kg/ha)							
	0	25	50	75	100	150	200	MEAN
	N content (kg/ha)							
NT mulch	20	30	50	55	55	50	65	45a
NT stubble	20	25	40	40	35	40	40	35a
CT grn manure	30	50	45	50	45	45	55	45a
CT stubble	25	35	45	50	45	60	50	45a
Mean	25	35	45	50	45	50	55	45

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Overall regression equation: $y=32.8 +.12x$ $R^2=.68$

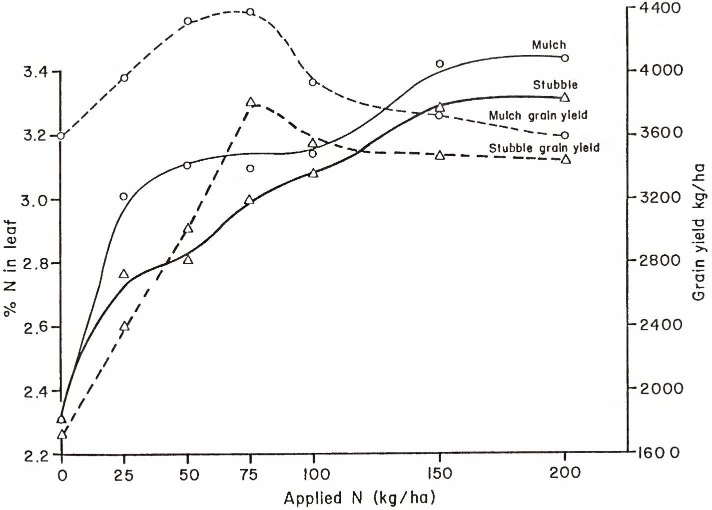

Fig. 2.1. Grain yield and leaf nitrogen of grain sorghum following crimson clover.

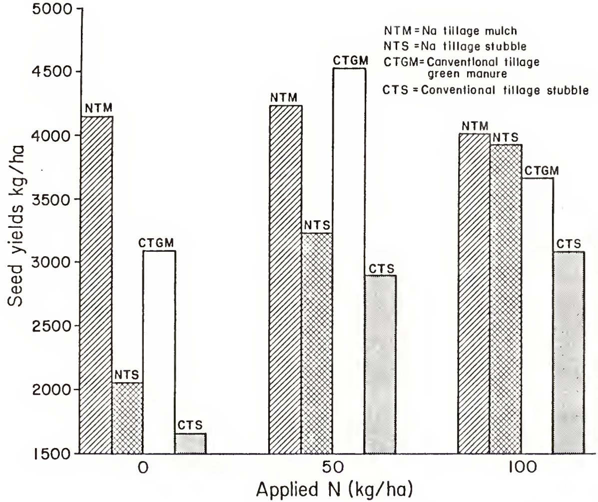

Fig. 2.2. Grain sorghum seed yields as affected by tillage and N rate when following crimson clover.

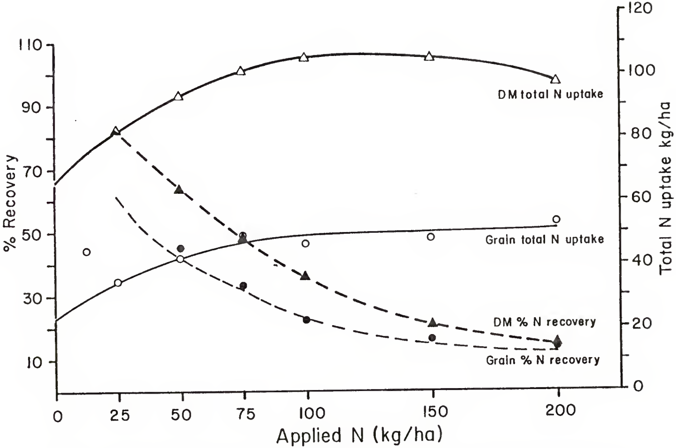

Fig. 2.3. Nitrogen uptake and recovery by grain sorghum following lupine.

CHAPTER 3
EFFECTS OF TILLAGE SYSTEMS AND NITROGEN FERTILIZATION ON NUTRIENT CONCENTRATION IN LEAVES OF GRAIN SORGHUM

Introduction

Utilization of winter legumes as an N source for summer grains or as a supplemental forage crop is gaining in popularity in the southern U.S. and in many countries in the sub-tropics. No-tillage (NT) seedbed preparation for the summer grain crop in these systems is also becoming a common practice, especially in those areas where soil erosion has become a problem or timeliness of planting the summer grain is a priority. Few studies to date have examined the effects of management of the winter legume or tillage on nutrient uptake in the summer grain crop.

Estes (1972) found K concentration in the ear leaf of corn (Zea mays L.) to be higher under NT management than with conventional tillage (CT) seedbed preparation but Ca, Mg, Zn, Mo, B, and Al concentrations were all lower with NT. Phosphorus, Fe, and Mn were not affected by tillage. Surface decomposition of plant residues was responsible for higher Ca, Mg, P, Mn, and Zn in the surface 7.5 cm with NT management as compared to CT (Hargrove et al., 1982). Juo and Lal (1979) also observed higher Ca and Mg in NT plots than in CT. However, higher Ca levels in CT soils than in those under NT management have also been noted (Blevins et al.,, 1977).

Nitrogen is undoubtedly the most common limiting nutrient to attaining maximum grain sorghum (Sorghum bicolor L. Moench) yields, but the effectiveness of applied N may be reduced if other essential plant nutrients are present in limited amounts or in proportions not suitable to plant growth. Lockman (1972) reported critical nutrient level (CNL) ranges for several elements for grain sorghum production. He found that N and P levels in leaf tissue of sorghum were well correlated with grain yield but that leaf K levels were more irregular and not as well correlated. Zinc levels exhibited a curvilinear correlation with grain yield, the correlation becoming negative as yields increased above the 6280 kg/ha level.

In a nutrient uptake corn study, Ca and Mg correlated with grain yield in NT plots, and Mn decreased and P decreased slightly with increasing rates of applied N (Lal, 1974). Touchton et al., (1982) found only leaf Cu to be affected by N, increasing linearly as N increased (R^2=0.74). When a winter crop of crimson clover (Trifolium incarnatum L.) was removed prior to sorghum seeding, sorghum leaf P was reduced, and in one year leaf K was reduced.

Nutrient interactions in grain sorghum are not well documented but several studies have investigated particular ratios and interactions. More than half of the total nutrient uptake in the vegetative growth of grain sorghum occurs in early growth (Jacques et al., 1975). The authors observed that Cu and Zn were translocated from vegetative growth to the head as grain developed but that Mn was not. Kuo and Mikkelson (1981) found high soil P levels to enhance Mn uptake but reduce Fe uptake (or at least translocation) in grain sorghum. Nutrient uptake generally increases with yield but total nutrient contents may vary widely with location, soil types, and hybrids (Fribourg et al., 1979).

The objective of this study was to examine the effect of tillage, legume management, and N fertilization on nutrient concentrations and contents of grain sorghum. Nutrient concentration in the diagnostic leaf, whole plant at maturity, and sorghum seed was monitored.

Materials and Methods

The experiment was conducted in 1982 and 1983 on an Arredondo fine sand, a member of the loamy silicious hyperthermic family of the Grossarenic Paleudults. The soil is fairly well-drained but has a slightly compacted layer at 20 to 30 cm and is high in residual phosphates. Two separate experiments were conducted at the Gainesville, Florida site. The first examined a crimson clover/grain sorghum system and the second, a blue lupine/grain sorghum system.

Both experiments utilized a randomized complete split plot design with five replications. Four main treatments were a combination of legume management plus tillage of the sorghum seedbed and included 1) no-tillage into legume mulch; 2) no-tillage sorghum with the legume removed; 3) conventional-tillage, legume mulched; and 4) conventional-tillage, legume removed. Subtreatments consisted of seven rates of N fertilizer; 0, 25, 50, 75, 100, 150, and 200 kg N/ha.

Clover/Sorghum System

The cropping system was fall-planted crimson clover followed by grain sorghum. The soil was tilled to a depth of 15 cm with a rototiller before legume establishment. The crimson clover (cultivar 'Dixie') was planted at 25 kg/ha in early November. Clover seeds were inoculated and planted in 25 cm rows with a Tye drill. Potassium, Mg, and S were applied at planting according to soil test recommendations. No herbicides were employed on the clover; however, in 1983, 2.2 kg a.i. glyphosate (N-phosphoromethylglycine)/ha was applied preplant when rain delayed planting after tillage was completed. In the spring, clover was sampled for DM yield and nutrient concentration, then mowed to a height of 7cm and removed or left standing as the treatment dictated. The clover mulch was killed (on NT plots) with an application of paraquat (1,1', dimethyl, 4,4' bipyridinium ion present as the dichloride salt plus 236 mL Ortho X77 surfactant/378 L water) and 2, 4-D (2,4-dichlorophenoxy acetic acid) immediately following sorghum planting. May-planted grain sorghum (variety 'GK 802G') was seeded at 9 kg/ha with a 25-cm spacing in a Tye drill in 1982. A Brown-Hardin super seeder with 76-cm row spacings was used in 1983 to facilitate weed control by allowing a post-directed herbicide application.

Nitrogen was applied as NH_4NO_3 at seven rates; 0, 25, 50, 75, 100, 150, and 200 kg N/ha in split applications, the first immediately after planting and the second 4 weeks later. A post-directed application of paraquat was applied to the sorghum at the rate of 0.28 kg a.i./ha 5 weeks after emergence.

Clover whole-plant samples were taken just prior to sorghum planting. Grain sorghum was sampled at early heading (10 to 15 samples consisting of 3rd leaf from the head) and again at maturity (whole-plant). All plant samples were dried at 70 C for a minimum of 48 hours prior to weighing, then chopped in a mulching machine (Amerind MacKissic), and ground in a Wiley mill to pass a 1-mm screen.

Nitrogen concentration was determined by a microKjeldahl procedure (Bremmer, 1965) as modified by Gallaher et al. (1976). A 100-mg sample of ground plant tissue was placed into a 75-mL digestion tube along with two boiling chips, 3.2 g of catalyst (90% anhydrous K_2SO_4: 10% anhydrous $CuSO_4$) and 10 mL concentrated H_2SO_4. Samples were digested for 3 hours at 380 C (Gallaher et al., 1975b). After they were diluted to 75 mL volume they were analyzed colorimetrically using an autoanalyzer.

Phosphorus, K, Ca, Mg, Cu, Zn, Mn, and Fe concentrations in plant tissue were determined by weighing 1.0 g of ground plant material into a 50-mL pyrex beaker and ashing at 480 C for a minimum of 6 hours. After cooling, 2 mL of concentrated HCl were added to the ash and the mixture was slowly heated until dry. An additional 2 mL of HCl and approximately 15 mL of water were added to the beakers after cooling. The mixture was covered with a watch glass and digested for 30 minutes on low heat. Solutions were diluted to 100 mL and stored in plastic vials. Phosphorus was determined colorimetrically, K by flame emission spectrophotometry, and the others by atomic absorption spectrophotometry.

Soils were sampled twice during each cropping year, once prior to legume establishment and again at sorghum harvest. Soil was sampled to a depth of 20 cm in a single increment, except the last sampling date in 1983, when an additional 20 to 40 cm increment was taken. All soil samples were air-dried and sieved to pass a 2-mm screen. Total soil N was determined by the modified microKjeldahl procedure described above, except that a 2 g sample was used. Extracts for mineral analysis were obtained by mixing 5 g soil with 20 ml 0.05 M HCl + 0.025 M (1/2 H_2SO_4) and shaking 5 minutes before filtration.

Plant content was determined by multiplying concentration of the plant element by total plant dry matter (DM). Soil content was determined by multiplying concentration in the soil by soil weight in the plow layer of a hectare.

Lupine/Sorghum System

The second experiment was identical to experiment one except that the system investigated was blue lupine (Lupinus angustifolius)/grain sorghum. As the two experiments were side by side in the field, field operations were scheduled for both experiments simultaneously. All sampling, harvest and pesticide applications were conducted at the same time for both experiments. The one exception was that, since the lupine (cultivar 'Tift blue') had no regrowth after mowing, it was not sprayed with paraquat prior to sorghum planting as was the crimson clover. Laboratory analysis was as described above.

Statistical analyses included analysis of variance for a split plot design. Significantly different tillage means were separated by the Duncan's Multiple Range Tests for significance at the 0.05 level of probability. Regression analysis was preformed on responses affected by N rate.

Results and Discussion

Crimson Clover/Grain Sorghum System

Crimson clover DM and nutrient content yields for whole plant at harvest are given in Table 3.1. When clover was cut for forage, over 90% of the total above-ground clover residue was removed, leaving the clover root system and 10% of the residue still in the field.

Nitrogen in the third leaf from the head at early bloom was affected both by tillage and applied N. Both the NT and CT treatments where clover residue was left were higher in leaf N values at most N rates (Table 3.2). There was no difference between NT and CT seedbed preparation when clover residue management was the same for both tillage operations. When averaged across tillage treatments, applied N affected leaf N in a linear manner, ranging from a low of 2.29% at the 0 kg N/ha rate to a high of 3.38% at the 200 kg N/ha rate. Average leaf N levels did not meet Lockman's (1972) proposed critical nutrient level (CNL) of 3.0% N until the 100 kg N/ha rate of applied N in stubble treatments but had attained this level at the 25 kg N/ha rate in mulch treatment. Correlations between leaf N and grain sorghum yields are discussed in an earlier paper (Eylands and Gallaher, 1984).

Leaf P increased from 0.54% at the 0 kg N/ha rate to 0.58% at the 25 kg N/ha rate and did not change with further increments of applied N. Phosphorus was lower in NT-stubble treatments, a trend noted by Touchton et al. (1982) in a similar Georgia study. Values for leaf P were higher than reported in other studies (Lockman, 1972; Touchton, 1982), probably due to the high levels of available P common to many north Florida soils.

Potassium in the diagnostic leaf decreased with applied N, ranging from 1.78% at the 0 kg N/ha rate to 1.56% at the 200 kg N/ha rate (Table 3.3). Tillage did not affect leaf K but when clover residue was removed both NT and CT treatments had lower values than if the residue was left. Since no fertilizer K was applied to the sorghum crop, the higher leaf K values for mulch treatments is likely due to K recycled from the decomposing clover residue.

Leaf Mg responded in a similar manner as P, increasing from the 0 to the 25 kg N/ha rate but stabilizing thereafter (Table 3.4). There was a tendency for the NT mulch treatment to exhibit higher leaf Mg levels at every N rate.

Leaf micronutrients (Fe, Zn, Mn, and Cu) were all affected by tillage and N rates (Tables 3.5-3.8). Iron, Zn and Mn all increased linearly with N rate and were higher in mulch treatments than when clover residue was removed, but did not respond to applied N beyond the 25 kg N/ha rate.

In contrast, analysis of sorghum whole plant at maturity showed no response of P, K, Fe, Zn, Mn or Cu to tillage or applied N (Table 3.9). Whole plant N increased from 1.09% to 1.38% from the lowest to highest N rate. Calcium and Mg increased from 0.16% to 0.20% and 0.22% to 0.26%, respectively, over the range of applied N.

Only N in the sorghum grain was affected by tillage, with mulched treatments having higher grain N levels than when clover residue was removed. All of the other nutrients measured were influenced by N rate, except Fe and Zn (Table 3.10). Contrary to observations in the diagnostic leaf, where K levels decreased while Ca and Mg levels increased with applied N (Fig. 3.1), levels of all three cations increased as N was applied. The relative amount of increase, however, was much smaller for K than for Ca and Mg. Grain Mn, Zn, and Cu also increased with applied N.

Lupine/Grain Sorghum System

Lupine DM yields and nutrient concentrations for whole plant at harvest are given in Table 3.11. At the time of cutting, the lupine crop was at early bloom stage and had attained a height of 1.00 m. As lupine exhibits no regrowth capabilities at this stage and it was desired to initiate decomposition of the residue by improving the lupine-soil contact, the mulch treatments were mowed prior to sorghum planting.

Method of tillage and lupine management affected leaf concentrations of the diagnostic leaf for P only (Table 3.12). Conventional tillage treatments contained higher levels of P than no-tillage treatments. In each tillage treatment, plots that had 25 kg N/ha applied had substantially higher P levels than at the 0 kg N/ha rate, but the response to additional increments was slight.

Applied N increased the leaf concentrations of all other nutrients except Cu, which it did not affect, and K, which decreased as applied N increased (Table 3.13). Leaf P and Zn were not increased beyond the 25 kg N/ha rate, which was also the point of maximum grain yields. Concentrations of Ca, Mg, Fe, and Mn were highest for the 200 kg N/ha treatment.

No tillage differences for mature whole plant concentrations of any nutrient were noted. Applied N increased concentrations of N, Ca, Mg, and Cu (Table 3.14). Contrary to observations on the diagnostic leaf, lower K levels in the whole plant at maturity did not accompany higher Ca and Mg levels. The Ca:Mg ratios were approximately 1:1 in the diagnostic leaf and 1:2 in the mature whole plant.

Nutrient concentrations of the sorghum grain were not affected by tillage (Table 3.15). Applied N increased concentrations of N, P, K, Ca, Mg, and Mn in sorghum grain. Zinc, Fe, and Cu were not affected.

Table 3.1. Crimson clover dry matter yields and nutrient contents.

	DM	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
					kg/ha					
Mean	6680	194	28	71	25	153	1.3	0.4	0.5	0.1

Table 3.2. Effects of tillage and N rate on leaf N (3rd leaf from head at early bloom) in grain sorghum following crimson clover.

Tillage	N applied (kg/ha) 0	25	50	75	100	150	200	MEAN
	% N							
NT mulch	2.58a	3.11a	3.01ab	2.92a	3.12a	3.41a	3.34ab	3.06
NT stubble	2.29a	2.82b	2.79b	2.82a	3.01a	3.28ab	3.42ab	2.92
CT grn manure	2.12a	2.97ab	3.27a	3.19a	3.20a	3.53a	3.53a	3.11
CT stubble	2.15a	2.80b	2.74b	2.90a	2.99a	3.10b	3.23b	2.84
Mean	2.29	2.92	2.95	2.96	3.08	3.33	3.38	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=2.72 +0.006x -0.00001x^2$	0.59
NT stubble	$y=2.42 +0.008x -0.00002x^2$	0.65
CT green manure	$y=2.37 +0.015x -0.00005x^2$	0.81
CT stubble	$y=2.32 +0.010x -0.00003x^2$	0.79

Table 3.3. Effects of tillage and N rate on leaf K (3rd leaf from head at early bloom) in grain sorghum following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	% N							
NT mulch	2.02a	1.82a	1.93a	2.00a	1.78a	1.82a	1.69a	1.87
NT stubble	1.65b	1.75a	1.61b	1.53a	1.45a	1.45b	1.49a	1.56
CT grn manure	1.68b	1.63a	1.77ab	1.68a	1.73a	1.79a	1.55a	1.69
CT stubble	1.79ab	1.67a	1.63b	1.66a	1.74a	1.53b	1.54a	1.65
Mean	1.78	1.72	1.73	1.72	1.67	1.66	1.56	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=1.94 -0.002x$	0.21
NT stubble	$y=1.82 -0.005x$	0.43
CT green manure	$y=1.81 -0.002x$	0.18
CT stubble	$y=1.77 -0.003x$	0.29

Table 3.4. Effects of tillage and N rate on leaf Mg (3rd leaf from head at early bloom) in grain sorghum following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	% Mg							
NT mulch	0.25a	0.28a	0.31a	0.30a	0.32a	0.30a	0.27a	0.29
NT stubble	0.22a	0.24b	0.26b	0.25b	0.25b	0.26b	0.29a	0.25
CT grn manure	0.21a	0.27ab	0.26b	0.27ab	0.28b	0.30a	0.24a	0.27
CT stubble	0.23a	0.24b	0.25b	0.25b	0.27b	0.29ab	0.25a	0.26
Mean	0.23	0.26	0.27	0.27	0.28	0.29	0.28	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=0.26 +0.001x -0.00005x^2$	0.53
NT stubble	$y=0.23 +0.002x -0.00003x^2$	0.38
CT green manure	$y=0.22 +0.001x -0.00003x^2$	0.48
CT stubble	$y=0.23 +0.001x -0.00002x^2$	o.41

Table 3.5. Effects of tillage and N rate on leaf Fe (3rd leaf from head at early bloom) in grain sorghum following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	ppm							
NT mulch	66a	78a	86a	88a	86a	88a	85ab	82
NT stubble	58a	72a	82ab	78ab	76ab	76a	82ab	74
CT grn manure	54a	68a	76ab	76ab	80ab	88a	94a	77
CT stubble	62a	72a	68b	72b	70b	80a	74b	72
Mean	60	73	78	78	78	83	84	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=69 +0.34x -0.01x^2$	0.51
NT stubble	$y=64 +0.19x -0.006x^2$	0.35
CT green manure	$y=58 +0.31x -0.007x^2$	0.68
CT stubble	$y=63 +0.19x -0.007x^2$	0.44

Table 3.6. Effects of tillage and N rate on leaf Zn (3rd leaf from head at early bloom) in grain sorghum following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	ppm							
NT mulch	26a	29a	31a	32a	31a	34a	31a	30
NT stubble	22a	25ab	26bb	24b	26b	25b	28a	25
CT grn manure	21a	27ab	26b	27b	27ab	29ab	30a	27
CT stubble	20a	24b	23c	25b	27ab	26b	28a	25
Mean	22	26	26	27	28	29	29	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=26.1 +0.10x -0.0004x^2$	0.48
NT stubble	$y=22.9 +0.03x -0.0003x^2$	0.32
CT green manure	$y=22.5 +0.07x -0.0002x^2$	0.36
CT stubble	$y=21.0 +0.08x -0.0002x^2$	0.57

Table 3.7. Effects of tillage and N rate on leaf Mn (3rd leaf from head at early bloom) in grain sorghum following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	ppm							
NT mulch	30a	36a	35a	38a	38a	43a	45a	38
NT stubble	27a	32a	31a	26c	30a	34a	36bc	31
CT grn manure	26a	37a	32a	34ab	37a	43a	41ab	36
CT stubble	26a	31a	29a	29bc	34a	36a	31c	31
Mean	28	34	32	32	35	39	38	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=31 +0.09x -0.0001x^2$	0.43
NT stubble	$y=29 -0.01x +0.0002x^2$	0.29
CT green manure	$y=28.5 +0.13x -0.0003x^2$	0.47
CT stubble	$y=26.4 +0.11x -0.0003x^2$	0.28

Table 3.8. Effects of tillage and N rate on leaf Cu (3rd leaf from head at early bloom) in grain sorghum following crimson clover.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	ppm							
NT mulch	6	5	5	7	6	7	6	5.8a
NT stubble	4	7	7	7	7	7	6	6.5a
CT grn manure	5	6	5	7	6	6	7	5.8a
CT stubble	6	8	7	7	6	6	6	6.6a
Mean	5.2	6.6	5.8	6.7	6.4	6.4	6.3	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Regression equation: $y= 5.5 -0.02x +0.0005x^2-0.000002x^3$ $R^2=0.38$

Table 3.9. Nutrient concentrations in sorghum whole plant at maturity as affected by N fertilization in a crimson clover/grain sorghum system.

	N applied (kg/ha)						
Tillage	0	25	50	75	100	150	200
	%						
N	1.09	1.11	1.11	1.20	1.17	1.33	1.38
Ca	0.16	0.19	0.17	0.19	0.19	0.19	0.20
Mg	0.22	0.23	0.23	0.25	0.24	0.25	0.26

P, K, Mn, Zn, Fe, Cu not affected

Element	Regression equation	R^2
N	$y=1.07 +0.002x$	0.59
Ca	$y=0.16 +0.0004x -0.00001x^2$	0.28
Mg	$y=0.22 +0.002x$	0.31

Table 3.10. Nutrient concentrations in sorghum grain as affected by N fertilization in a crimson clover/grain sorghum system.

	N applied (kg/ha)						
Tillage	0	25	50	75	100	150	200
				%			
N	1.31	1.43	1.43	1.56	1.58	1.84	1.90
P	0.65	0.72	0.73	0.79	0.83	0.86	0.92
K	0.66	0.70	0.70	0.75	0.78	0.77	0.81
Ca	0.22	0.24	0.25	0.29	0.34	0.38	0.40
Mg	0.29	0.32	0.32	0.36	0.38	0.40	0.42
				ppm			
Mn	27	31	29	33	35	39	40
Zn	30	35	37	42	43	50	51

Element	Regression equation	R^2	Element	Regression Equation	R^2
N	$y=1.31 +0.003x$	0.72	Ca	$y=0.29 +0.11x -0.003x^2$	0.52
P	$y=0.67 +0.002x$	0.50	Mn	$y=27 +0.1x$	0.52
K	$y=0.66 +0.001x -0.0003x^2$	0.42	Zn	$y=33 +0.10x$	0.54

Table 3.11. Lupine dry matter yields and nutrient contents.

	DM	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
					kg/ha					
Mean	8000	172	24	74	25	168	1.3	0.4	0.1	0.1

Table 3.12. Effects of tillage and N rate on leaf P (3rd leaf from head at early bloom) in grain sorghum following lupine.

	N applied (kg/ha)							
Tillage	0	25	50	75	100	150	200	MEAN
	%							
NT mulch	0.49a	0.61a	0.61a	0.63a	0.57b	0.50a	0.62ab	0.57
NT stubble	0.50a	0.59a	0.57a	0.51b	0.60b	0.57ab	0.50b	0.54
CT grn manure	0.52a	0.59a	0.64a	0.61	0.58b	0.63a	0.61ab	0.60
CT stubble	0.52a	0.63a	0.63a	0.67	0.67a	0.64a	0.68a	0.63
Mean	0.51	0.60	0.61	0.60	0.60	0.58	0.60	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Table 3.13. Nutrient concentrations in sorghum leaf as affected by N fertilization in a lupine/grain sorghum system.

	N applied (kg/ha)						
Tillage	0	25	50	75	100	150	200
				%			
N	2.40	2.95	2.98	3.22	3.05	3.25	3.32
P	0.51	0.60	0.61	0.60	0.60	0.58	0.60
K	1.69	1.69	1.63	1.55	1.57	1.51	1.53
Ca	0.33	0.32	0.33	0.34	0.34	0.39	0.39
Mg	0.26	0.32	0.33	0.34	0.34	0.39	0.39
				ppm			
Fe	63	79	76	78	75	80	87
Mn	26	32	33	34	35	39	39
Zn	21	26	27	27	26	28	27

Element	Regression equation	R^2	Element	Regression Equation	R^2
N	$y=2.44 +0.02x -0.0001x^2$	0.66	Mg	$y=0.24 +0.0006x -0.00002x^2$	0.28
P	$y=0.51 +0.004x -0.0003x^2$	0.31	Fe	$y=63 +4.4x +0.04x^2-0.0001x^3$	0.29
K	$y=1.63 -0.001x$	0.42	Mn	$y=27 +0.1x$	0.39
Ca	$y=0.36 +0.0007x$	0.42	Zn	$y=21 +0.16x -0.001x^2+0.00003x^3$	0.44

Table 3.14. Nutrient concentrations in sorghum whole plant at maturity as affected by N fertilization in a lupine/grain sorghum system.

	N applied (kg/ha)						
Tillage	0	25	50	75	100	150	200
				%			
N	1.05	1.17	1.19	1.28	1.16	1.28	1.37
Ca	0.15	0.16	0.17	0.18	0.17	0.20	0.19
Mg	0.23	0.24	0.24	0.26	0.24	0.26	0.26
				ppm			
Cu	3	3	4	4	4	4	4

P, K, Fe, Mn, and Zn not affected

Element	Regression equation	R^2
N	$y=1.10 +0.001x$	0.49
Ca	$y=0.16 +0.002x$	0.23
Mg	$y=0.23 +0.001x$	0.31
Cu	$y=3 +0.02x -0.0005x^2$	0.21

Table 3.15. Nutrient concentrations in sorghum grain as affected by N fertilization in a lupine/grain sorghum system.

	N applied (kg/ha)						
Tillage	0	25	50	75	100	150	200
				%			
N	1.25	1.46	1.52	1.65	1.64	1.81	1.82
P	0.64	0.79	0.76	0.84	0.81	0.82	0.87
K	0.64	0.75	0.74	0.78	0.77	0.83	0.82
Ca	0.27	0.30	0.30	0.32	0.42	0.42	0.36
Mg	0.28	0.36	0.35	0.39	0.38	0.44	0.42
				ppm			
Mn	29	35	34	37	38	44	42

Zn, Fe, Cu not affected

Element	Regression equation	R^2
N	$y=1.27 + 0.006x - 0.00001x^2$	0.68
P	$y=0.65 + 0.005x - 0.00004x^2$	0.29
K	$y=0.66 + 0.002x - 0.00005x^2$	0.38
Ca	$y=0.27 - 0.002x + 0.00002x^2$	0.37
Mg	$y=0.29 + 0.0015x - 0.00004x^2$	0.43
Mn	$y=31 + 0.06x$	0.37

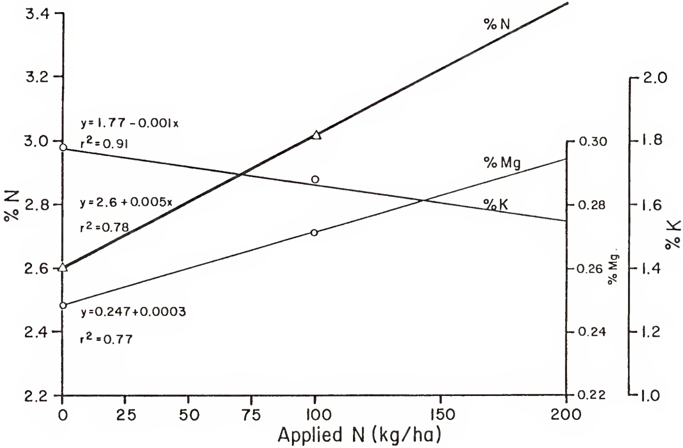

Fig. 3.1. Effect of N rate on leaf N, K, and Mg in the diagnostic leaf of grain sorghum following crimson clover.

CHAPTER 4
NUTRIENT CYCLING IN A WINTER LEGUME/GRAIN SORGHUM CROPPING SYSTEM

Introduction

Nye and Greenland (1960), in explaining the seemingly large quantities of vegetative matter produced on acid tropical soils in rainforests, described a more or less "closed" system of nutrient cycling. Actively growing plants year-round with well developed root systems afforded little opportunity for nutrient loss from leaching or surface runoff. No harvest was taken so most plant-essential nutrients were either contained in the phytomass of the system or in actively decomposing forest litter. While approximating this system in modern agricultural soils is not possible, recent advances in multicropping and no-tillage (NT) management may help considerably to reduce nutrient losses from any agricultural system.

The relatively low fertilizer requirements of long-term, NT, small grain/soybean (Glycine max L.) systems (Barnett et al., 1980) has been a major reason for their increase in popularity in the United States. Even after soybean grain has been harvested, N in the remaining residue may be adequate for acceptable small grain yields if it was all mineralized (Post, 1983). Other studies utilizing a green-manure legume crop have indicated that enough of the legume tissue N may be mineralized for maximum grain yield production in a subsequent cereal crop (Gallaher, 1982 and Touchton et al., 1982).

Ways in which nutrient cycling may be improved include 1)Multicropping-to maintain an actively growing crop and root system present as long as possible so as to reduce nutrient leaching losses; 2) Crop rotation-to allow crops with different rooting patterns and nutrient requirements to take advantage of differences in distribution of nutrients in the soil. Legumes in succession with grass crops should help to increase N in the system; 3) Minimum tillage practices-to encourage soil OM maintainance or even buildup, which will in turn improve cation retension in the soil. No-tillage may also increase soil moisture holding capacities which in turn will reduce erosion and leaching losses and increase efficiency of uptake of available nutrients; 4) Residue management-leaving or returning all crop residues to the soil. Burning residues will result in the loss of some volatile nutrients such as N and S, as well as most of the C necessary as an energy source for microorganisms.

There are, however, many unanswered questions as to how and if NT practices will affect nutrient recycling. The results of several studies indicate that soil OM and N will be higher under NT management than with CT (Post, 1983 and Gallaher, 1980). Mineralization of N will probably be slower under NT conditions (Smith, 1979) and more N may be lost to denitrification under NT conditions (Smith et al., 1980). Increased water infiltration with subsoiling and NT could also increase N soil leaching losses (Lal, 1979). Shulte (1979) stated that NT management may result in accumulation of nutrients close to the soil surface only, and that occasional tillage may improve yields through repositioning essential plant nutrients.

There are studies showing more residual K under NT systems as compared to conventional tillage (CT) (Lal, 1979 and Triplett and Van Doren, 1969). Other research has shown little difference between NT and CT (Shear and Moschler, 1969). Still other works have shown an advantage for CT (Hargrove et al. 1982 and Post, 1983). As most K stays in the stem of cereal crops (Evans and Wardlaw, 1976) but is still being taken up during grain filling for such legumes as soybean (Henderson and Kamprath, 1970), it appears that cropping system, soil type and perhaps rainfall patterns all affect retention and recycling of K in multicropping systems.

Total soil Ca and Mg may actually increase in the 0 to 30cm layer with some cropping systems (Rao and Sharman, 1976 and Post, 1983). Calcium does not translocate well within a plant (Ohlrogge, 1963) so much of the total uptake during the growing season is returned to the soil upon decomposition of vegetative tissues. Data concerning micronutrient recycling under NT and CT regimes are scarce. Hargrove et al., (1982) found more Zn and Mn in NT surface soils, probably due to residue accumulations. In a rye (Secale cereal L.)/soybean double cropping study, Fe, Cu, Zn, and Mn were present at higher levels during early growth for both crops than at planting, indicating some immediate recycling from the previous crop (Post, 1983).

Applied N fertilizers are known to increase the total uptake of many plant nutrients, both through increased DM yields and increased plant concentrations (Brawand and Hossner, 1976 and Eylands and Gallaher, 1984). Moschler et al. (1975) warned that high N rates may promote leaching of Ca and Mg.

The objective of this study was to examine nutrient cylcing in a winter legume/grain sorghum study. The effects of legume management, tillage, and N rate on nutrient contents of the two crops as well as nutrient balances in the soil were measured.

Materials and Methods

The experiment was conducted in 1982 and 1983 on an Arredondo fine sand, a member of the loamy silicious hyperthermic family of the Grossarenic Paleudults. The soil was fairly well-drained but had a slightly compacted layer at 20 to 30 cm and was high in residual phosphates. Two separate experiments were conducted at the Gainesville, Florida site. The first examined a crimson clover/grain sorghum system and the second, a blue lupine (Lupinus angustifolius)/grain sorghum system.

Both experiments utilized a randomized complete split plot design with five replications. Four main treatments were a combination of legume management plus tillage of the sorghum seedbed and included 1) no-tillage into legume mulch; 2) no-tillage sorghum with the legume removed; 3) conventional-tillage, legume mulched; and 4) conventional-tillage, legume removed. Subtreatments consisted of seven rates of N fertilizer; 0, 25, 50, 75, 100, 150, and 200 kg N/ha.

Clover/Sorghum System

The cropping system was fall-planted crimson clover followed by grain sorghum. The soil was tilled to a depth of 15 cm with a rototiller before legume establishment. The crimson clover (cultivar 'Dixie') was planted at 25 kg/ha in early November. Clover seeds were inoculated and planted in 25 cm rows with a Tye drill. Potassium, Mg, and S were applied at planting according to soil test recommendations. No herbicides were employed on the clover; however, in 1983, 2.2 kg a.i. glyphosate (N-phosphoromethylglycine)/ha was applied preplant when rain delayed planting after tillage was completed. In the spring, clover was sampled for DM yield and nutrient concentration, then mowed to a height of 7cm and removed or left standing as the treatment dictated. The clover mulch was killed (on NT plots) with an application of paraquat (1,1', dimethyl, 4,4' bipyridinium ion present as the dichloride salt plus 236 mL Ortho X77 surfactant/378 L water) and 2, 4-D (2,4-dichlorophenoxy acetic acid) immediately following sorghum planting. May-planted grain sorghum (cultivar Goldkist 'GK 802G') was seeded at 9 kg/ha with a 25 cm spacing in a Tye drill in 1982. A

Brown-Hardin super seeder with 76 cm row spacings was used in 1983 to facilitate weed control by allowing a post-directed herbicide application.

Nitrogen was applied as NH_4NO_3 at seven rates; 0, 25, 50, 75, 100, 150, and 200 kg N/ha in split applications, the first immediately after planting and the second 4 weeks later. A post-directed application of paraquat was applied to the sorghum at the rate of 0.28 kg a.i./ha 5 weeks after emergence.

Clover whole-plant samples were taken just prior to sorghum planting. Grain sorghum was sampled at early heading (10 to 15 samples consisting of 3rd leaf from the head) and again at maturity (whole-plant). All plant samples were dried at 70 C for a minimum of 48 hours prior to weighing, then chopped in a mulching machine (Amerind MacKissic) and ground in a Wiley mill to pass a 1-mm screen.

Nitrogen concentration was determined by a microKjeldahl procedure (Bremmer, 1965) as modified by Gallaher et al. (1976). A 100-mg sample of ground plant tissue was placed into a 75-mL digestion tube along with 2 boiling chips, 3.2 g of catalyst (90% anhydrous K_2SO_4: 10% anhydrous $CuSO_4$) and 10 mL concentrated H_2SO_4. Samples were digested for 3 hours at 380 C (Gallaher et al., 1975b). After they were diluted to 75-mL volume they were analyzed colorimetrically using an autoanalyzer.

Phosphorus, K, Ca, Mg, Cu, Zn, Mn, and Fe concentrations in plant tissue were determined by weighing 1.0 g of ground plant material into a 50-mL pyrex beaker and ashing at 480 C for a minimum of 6 hours. After cooling, 2 mL of concentrated HCl were added to the ash and the mixture was slowly heated until dry. An additional 2 mL of HCl and approximately 15 mL of water were added to the beakers after cooling. The mixture was covered with a watch glass and digested for 30 minutes on low heat. Solutions were diluted to 100 mL and stored in plastic vials. Phosphorus was determined colorimetrically, K by flame emission spectrophotometry, and the others by atomic absorption spectrophotometry.

Soils were sampled twice during each cropping year, once prior to legume establishment and again at sorghum harvest. Soil was sampled to a depth of 20 cm in a single increment except the last sampling date in 1983, when an additional 20 to 40 cm increment was taken. All soil samples were air-dried and sieved to pass a 2-mm screen. Total soil N was determined by the modified microKjeldahl procedure described above, except that a 2 g sample was used. Extracts for mineral analysis were obtained by mixing 5 g soil with 20 mL 0.05 M HCl + 0.025 M (1/2 H_2SO_4) and shaking 5 minutes before filtration.

Plant content was determined by multiplying concentration of the plant element by total plant dry matter (DM). Soil content was determined by multiplying concentration in the soil by soil weight in the plow layer of a hectare.

Lupine/Sorghum System

The second experiment was identical to experiment one except that the system investigated was lupine (cultivar 'Tift blue')/grain sorghum. As the two experiments were side by side in the field, field operations were scheduled for both experiments simultaneously. All sampling, harvest and pesticide applications were conducted at the same time for both experiments. The one exception was that, since the lupine had no regrowth after mowing, it was not sprayed with paraquat prior to sorghum planting as was the crimson clover. Laboratory analysis was as described above.

Statistical analyses included analysis of variance for a split plot design. Significantly different tillage means were separated by the Duncan's Multiple Range Test for significance at the 0.05 level of probability. Regression analysis was performed on responses affected by N rate.

Results and Discussion

Clover/Grain Sorghum System

Crimson clover and grain sorghum DM and nutrient contents are given in Table 4.1. The grain sorghum figures are 2-year averages over tillage treatments at the point of maximum grain yield and represent whole plant at maturity. Since some nutrients had already moved out of the sorghum and leaf senescence was beginning, these levels would be somewhat lower than maximum nutrient contents of the grain sorghum plant. It is evident that, should complete mineralization of the clover take place and if recovery of the nutrients by sorghum was high, the clover would contain sufficient levels of all nutrients except P to produce maximum sorghum grain yields. Only a third of the N from a mulch crop may be available to the subsequent crop, however (Whiteman, 1980). Grain sorghum did respond to inorganic N up to the 50 kg/ha rate when following a mulched legume crop (Eylands and Gallaher, 1984).

As it was the purpose of this study to investigate the effect of tillage, legume management, and N rate on nutrient cycling within the system, orthogonal contrasts are given for the 0, 50, and 100 kg N/ha rates. In most instances, maximum grain yields were attained at the 50 kg N/ha rate although nutrient concentrations in grain were higher as applied N increased (Table 4.2).

Mulch treatments (clover residue left) had positive N balances for the 0 and 50 kg N/ha rate of applied N and became negative at the 100 kg N/ha rate (Tables 4.3 to 4.5). Mowed treatments (clover removed) had negative N balances at all N rates. This indicates that the clover was apparently able to supply enough N to provide for that removed by the sorghum grain plus that N still contained in the sorghum residue at the time of the final soil sampling. Grain yields were higher when 25 kg N/ha were added, however, this may have been due to a slower rate of mineralization if no inorganic N was added. As grain yields in non-mulch treatments were maximum at the 50 kg N/ha (1983) or 75 kg N/ha rate (1982), and sorghum whole plant contents were higher than the N loss from the system, it is also evident that the clover root system added some N to the system.

Final soil test levels for P exceeded initial values for all treatments, probably due to P uptake by both crops below the 20-cm depth. As soils in the region are prone to K and Mg deficiences, these nutrients were applied in the amounts of 32 and 13 kg/ha, respectively, before clover establishment. In both years of the experiment, K soil test values were unchanged. Higher N rates increased yields and K concentration in sorghum grain, thus about 30% more K was removed in the grain at the 100 kg N/ha rate than at the 0 kg N/ha rate. Soil Ca balance was not affected by mulching in a consistent manner, but tended to be lower at higher N rates even though the amount removed in the grain was not significantly higher. Magnesium balance also remained stable throughout the experiment. Past work on the same soils (Post, 1983 and Frasher, 1983) indicated that inorganic K must be added to the system to maintain soil K values.

Method of tillage affected only N and Ca balance (Tables 4.6-4.8). More Ca was retained in the 0 to 20 cm layer with CT except at the 0 kg N/ha rate, when NT management was favored. Conventional tillage also produced slightly higher final N levels, although both methods had negative N balances when more than 50 kg N/ha was applied.

Lupine/Grain Sorghum System

Lupine and grain sorghum DM and nutrient content yields are given in Table 4.9. Values for each crop represent 2-year averages and grain sorghum levels are averaged across tillage treatments and represent yields at the point of maximum grain yields.

Method of tillage, mulching, and N rate affected recycling of N and Ca while P, K, and Mg were either unaffected or had inconsistent responses. Applied N lowered N balance in mulched plots but had no effect in unmulched plots. Soil Ca levels were higher in unmulched treatments if inorganic N was applied. Nitrogen balance was lower with increasing N rates as the applied inorganic N was not efficiently recovered, regardless of tillage. Calcium balance was also adversely affected by applied N, probably due to both increased leaching losses (Moschler et al. 1975) and higher removal of Ca with higher N rates. Phosphorus balance was positive for all treatments while K and Mg remained stable or decreased slightly.

Conclusions

It is apparent from these two experiments that mulching a winter legume before grain sorghum planting may improve nutrient cycling of all measured nutrients except Ca. Even though final soil balances of P, K and Mg indicated little difference between mulched and unmulched treatments, the grain sorghum contents of all of these nutrients in the sorghum residue was higher with mulched treatments because DM yields were higher. Calcium recycling was best with CT green manure treatments and was adversely affected by addition of inorganic N. Although N balance was best at the 0 kg N/ha rate, the most efficient system for maximum grain yields and N recycling was the NT mulch or CT green manure treatments with an additional 25 to 50 kg N/ha, probably due to more rapid mineralization of legume N when a small amount of inorganic N is present.

Table 4.1. Dry matter and nutrient content yields for crimson clover and grain sorghum at maximum grain yield.

Crop	DM	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
Crimson clover	5800	170	26	65	23	111	1.1	0.3	0.5	0.1
Grain sorghum	9800	110	42	16	19	122	1.2	0.2	0.4	0.1

Table 4.2. Nutrient contents in sorghum grain as affected by N rate in a crimson clover/grain sorghum system.

	N applied (kg/ha)						
Element	0	25	50	75	100	150	200
	kg/ha						
N	36	45	53	63	58	67	67
P	18	23	27	32	30	31	33
K	18	22	26	30	28	28	29
Ca	6	8	9	12	12	14	14
Mg	8	10	12	15	14	15	15
Mn	0.8	1.0	1.1	1.2	1.4	1.4	1.4
Zn	0.9	1.1	1.4	1.7	1.6	1.8	1.8
Cu	0.1	0.1	0.1	0.2	0.2	0.2	0.2

Table 4.3. Effect of mulching on soil nutrient balance in a crimson clover/grain sorghum system at 0 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	+	-	+	-	+	-	+	-	+	-
	kg/ha									
Initial soil	1009	1009	121	121	62	62	557	557	83	83
Fertilizer	0	0	0	0	32	32	0	0	13	13
Removed in grain	48	25	23	13	25	12	8	5	11	6
Expected soil test level	961	984	98	108	69	82	549	552	85	90
Actual soil test level	991	980	142	154	68	87	588	588	106	104
Net gain or loss	+30	-4	+44	+46	-1	+5	+39	+36	+21	+14

+ = clover residue left
- = clover residue removed

Table 4.4. Effect of mulching on soil nutrient balance in a crimson clover/grain sorghum system at 50 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	+	-	+	-	+	-	+	-	+	-
	kg/ha									
Initial soil	1009	1009	121	121	62	62	557	557	83	83
Fertilizer	50	50	0	0	32	32	0	0	13	13
Removed in grain	65	42	32	32	31	21	10	9	14	10
Expected soil test level	995	1017	89	99	63	73	547	548	80	84
Actual soil test level	1117	920	163	135	79	91	504	462	80	87
Net gain or loss	+121	-97	+74	+36	+16	+18	-43	-86	0	+3

+ = clover residue left
- = clover residue removed

Table 4.5. Effect of tillage on soil nutrient balance in a crimson clover/grain sorghum system at 0 kg/ha applied N.

	N		P		K		Ca		Mg	
Parameter	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	kg/ha									
Initial soil	1009	1009	121	121	62	62	557	557	83	83
Fertilizer	0	0	0	0	32	32	0	0	13	13
Removed in grain	40	33	20	16	21	16	6	6	9	7
Expected soil test level	969	976	101	105	73	78	551	551	87	89
Actual soil test level	988	983	145	151	75	84	612	564	112	98
Net gain or loss	+19	+7	+44	+46	+2	+6	+61	+13	+25	+9

Table 4.6. Effect of tillage on soil nutrient balance in a crimson clover/grain sorghum system at 50 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	kg/ha									
Initial soil	1009	1009	121	121	62	62	557	557	83	83
Fertilizer	50	50	0	0	32	32	0	0	13	13
Removed in grain	53	53	29	26	27	25	8	11	12	12
Expected soil test level	1006	1006	92	95	67	69	549	546	84	84
Actual soil test level	1019	1064	132	151	89	81	438	528	83	85
Net gain or loss	+13	+58	+40	+56	+22	+12	-111	-18	-1	+1

Table 4.7. Effect of tillage on soil nutrient balance in a crimson clover/grain sorghum system at 100 kg/ha applied N.

	N		P		K		Ca		Mg	
Parameter	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	-kg/ha-									
Initial soil	1009	1009	121	121	62	62	557	557	83	83
Fertilizer	100	100	0	0	32	32	0	0	13	13
Removed in grain	62	54	31	30	30	28	13	12	14	13
Expected soil test level	1047	1055	90	91	64	66	544	545	80	81
Actual soil test level	995	1010	114	153	63	71	426	588	72	95
Net gain or loss	-52	-45	+24	+62	-1	+5	-118	+43	-8	+14

Table 4.8. Dry matter and nutrient content yields for lupine and grain sorghum at maximum grain yield.

Crop	DM	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
Lupine	8000	170	24	74	25	170	1.3	0.4	0.1	0.1
Grain sorghum	9770	111	42	16	19	122	1.2	0.2	0.4	0.1

Table 4.9. Effect of tillage on soil nutrient balance in a lupine/grain sorghum system at 0 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	kg/ha									
Initial soil	1046	1046	96	96	91	91	516	516	87	87
Fertilizer	0	0	0	0	32	32	0	0	13	13
Removed in grain	20	27	11	13	10	14	4	6	5	6
Expected soil test level	1026	1019	85	83	113	109	512	510	95	94
Actual soil test level	975	1074	95	104	118	99	498	540	86	92
Net gain or loss	-51	+55	+10	+21	+5	-10	-14	+30	-9	-2

Table 4.10. Effect of tillage on soil nutrient balance in a lupine/grain sorghum system at 50 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	kg/ha									
Initial soil	1046	1046	96	96	91	91	516	516	87	87
Fertilizer	50	50	0	0	32	32	0	0	13	13
Removed in grain	44	46	23	22	21	22	9	9	11	10
Expected soil test level	1052	1050	73	74	102	101	507	507	89	90
Actual soil test level	1059	1007	95	99	98	97	498	528	82	85
Net gain or loss	+7	-43	+22	+25	-4	-4	-9	+21	-7	-5

Table 4.11. Effect of tillage on soil nutrient balance in a lupine/grain sorghum system at 100 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	kg/ha									
Initial soil	1046	1046	96	96	91	91	516	516	87	87
Fertilizer	100	100	0	0	32	32	0	0	13	13
Removed in grain	45	45	24	20	22	20	13	10	11	10
Expected soil test level	1101	1101	72	76	101	103	503	506	89	90
Actual soil test level	1066	1072	98	102	94	108	480	486	79	73
Net gain or loss	-35	-29	+26	+26	-7	+5	-23	-20	-10	-17

Table 4.12. Effect of mulching on soil nutrient balance in a lupine/grain sorghum system at 0 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	+	-	+	-	+	-	+	-	+	-
	kg/ha									
Initial soil	1046	1046	96	96	91	91	516	516	87	87
Fertilizer	0	0	0	0	32	32	0	0	13	13
Removed in grain	25	23	13	11	12	12	5	4	6	5
Expected soil test level	1021	1023	83	85	111	111	511	512	94	95
Actual soil test level	1057	992	96	104	118	99	528	510	93	85
Net gain or loss	+36	-31	+13	+19	+7	-12	+17	-2	-1	-10

+ = lupine residue left
- = lupine residue removed

Table 4.13. Effect of mulching on soil nutrient balance in a lupine/grain sorghum system at 50 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	+	-	+	-	+	-	+	-	+	-
	kg/ha									
Initial soil	1046	1046	96	96	91	91	516	516	87	87
Fertilizer	50	50	0	0	32	32	0	0	13	13
Removed in grain	48	42	24	21	23	21	9	9	11	10
Expected soil test level	1048	1054	72	75	100	102	507	509	89	90
Actual soil test level	1036	1031	89	104	120	75	472	552	81	88
Net gain or loss	-12	-23	+17	+29	+20	-27	-35	+45	-8	-2

+ = lupine residue left
- = lupine residue removed

Table 4.14. Effect of mulching on soil nutrient balance in a lupine/grain sorghum system at 100 kg/ha applied N.

Parameter	N		P		K		Ca		Mg	
	+	-	+	-	+	-	+	-	+	-
	kg/ha									
Initial soil	1046	1046	96	96	91	91	516	516	87	87
Fertilizer	100	100	0	0	32	32	0	0	13	13
Removed in grain	50	40	24	21	23	20	13	10	12	10
Expected soil test level	1096	1086	72	75	100	103	503	506	88	90
Actual soil test level	1090	1047	98	103	109	94	456	510	75	76
Net gain or loss	-6	-39	+26	+28	+9	-9	-47	+4	-13	-14

+ = lupine residue left
- = lupine residue removed

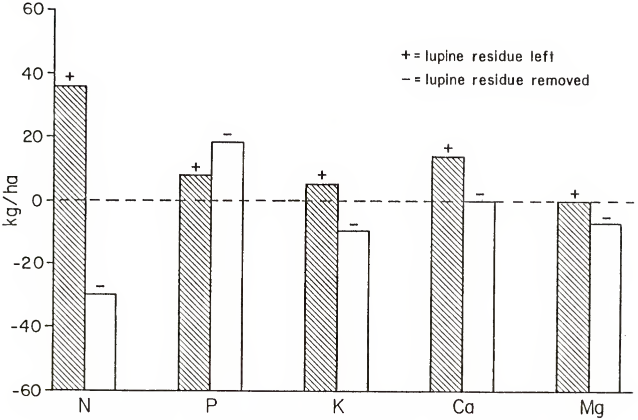

Fig. 4.1. Nutrient balances in the soil after a lupine/grain sorghum cropping system with 0 kg N/ha applied to the sorghum.

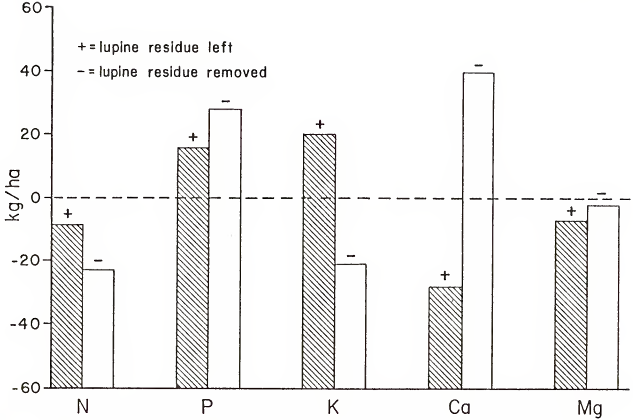

Fig. 4.2. Nutrient balances in the soil after a lupine/grain sorghum cropping system with 50 kg N/ha applied to the sorghum.

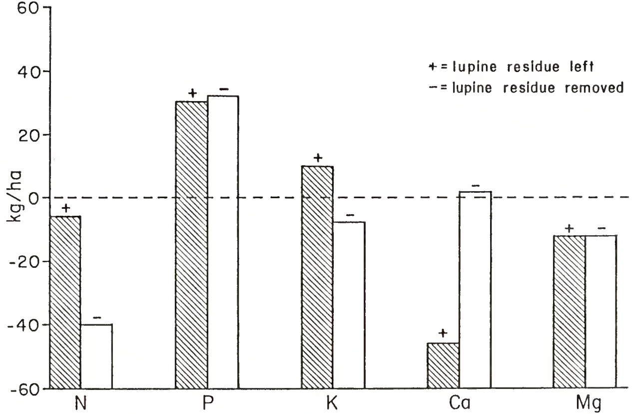

Fig. 4.3. Nutrient balances in the soil after a lupine/grain sorghum cropping system with 100 kg N/ha applied to the sorghum.

CHAPTER 5

NUTRIENT UPTAKE AND RECYCLING IN A CRIMSON CLOVER/CORN CROPPING SYSTEM.

Introduction

The utilization of legumes as an organic mulch and N source for subsequent cereal grain and forage crops is gaining in popularity in many regions of the U.S. When used in conjunction with minimum tillage practices, growers in some areas have been able to realize the combined benefits of reduced inorganic N inputs into the system, reduced soil erosional losses, better nutrient recycling, and increased soil moisture under no-tillage (NT) management.

It has been shown that legume mulches do not have to be incorporated for N to mineralize (Schrader et al., 1956 and Triplett et al., 1979). However, nitrogen mineralization under NT regimes may be slower than that under conventional tillage (CT) (Smith, 1979). In addition, there is some evidence that denitrification (Smith et al., 1980) and leaching (Thomas et al., 1979) losses of N may be higher under NT management. Despite these observations, soil N and OM are frequently built up or better maintained under NT compared to CT (Blevins et al., 1977 and Lal, 1976).

Winter legume/corn (Zea mays L.) multicropping systems have been the subject of several recent investigations. Hairy vetch (Vicia villosa Roth) had N contents of over 200 kg/ha and provided close to one-half this amount to the following NT planted corn crop (Ebelher et al., 1984). In the same study, corn still responded to an additional 100 kg/ha applied N. In other studies, the winter legume has provided adequate N for maximum cereal grain yields (Touchton et al., 1982 and Gallaher, 1980).

Tillage practices also affect concentrations of plant-essential nutrients in the soil surface (Hargrove et al., 1982) and this nutrient uptake may be affected both by mulching and tillage. Estes (1972) found only K uptake in corn to be higher under NT conditions as compared to CT, while P uptake was unaffected and Ca, Mg and micronutrient uptake was higher under CT. Calcium and Mg uptake may be inhibited if soil moisture is higher in NT conditions and more K is in solutions.

Critical nutrient levels (CNL) for corn were first established by Tyner (1946). He proposed CNL levels of 2.9% N, 0.295% P, and 1.3% K for the sixth leaf at silking. Since then many CNL values or ranges of values have been proposed, but the concensus of the literature places CNL levels at approximately 2.75 to 3.50% for N, 0.25 to 0.40 for P, and 1.5 to 2.5% for K, when measured at the ear leaf at silking.

Nintey-three fertility experiments on corn were analyzed by regression analysis to determine CNL levels over a wide range of soils, cultivars, available moisture, and soil fertility levels (Dumenil, 1961). The author used CNL levels based on 95% of maximum yield and concluded that CNL levels were not single points or even narrow ranges, but could have a broad range because of the multitude of possible interactions.

The primary objective of this experiment was to determine the amount of N provided to corn by a winter cover crop of crimson clover (Trifolium incaratum L.). Additionally, corn response to inorganic N and nutrient recycling in the system was examined.

Materials and Methods

The experiment was conducted in 1983 on an Arredondo fine sand, a member of the loamy silicious hyperthermic family of the Grossarenic Paleudults. The soil was fairly well-drained but had a slightly compacted layer at 20 to 30 cm and was high in residual phosphates. The Green Acres Agronomy farm near Gainesville, Florida, was the experimental site. A crimson clover/corn multicropping system was examined.

A randomized complete split plot design with four replications was the design utilized. Four main treatments were a combination of legume management plus tillage of the corn seedbed and included 1) corn planted no-tillage into legume mulch; 2) no-tillage corn with the legume removed; 3) conventional-tillage, legume green manured; and 4) conventional-tillage, legume removed. Subtreatments consisted of four rates of N fertilizer; 0, 37, 75, and 150 kg N/ha.

The cropping system was fall-planted crimson clover followed by corn. The soil was tilled to a depth of 15 cm with a rototiller before legume establishment. The crimson clover (cultivar 'Dixie') was planted at 25 kg/ha in early November. Clover seeds were inoculated and planted in 25 cm rows with a Tye drill. Potassium, Mg, and S were applied at planting according to soil test recommendations. No herbicides were employed on the clover; however, 2.2 kg a.i. glyphosate (N-phosphoromethylglycone)/ha were applied preplant when rain delayed planting after tillage was completed. In the spring, clover was sampled for DM yield and nutrient concentration, then mowed to a height of 7 cm and removed or left standing as the treatment dictated. The clover mulch was killed (on NT plots) with an application of paraquat (1,1', dimethyl, 4,4' bipyridinium ion present as the dichloride salt plus 236 mL Ortho X77 surfactant/378 L water) and 2, 4-D (2,4-dichlorophenoxy acetic acid) immediately following sorghum planting. April-planted corn (variety 'Funks 4507A') was seeded at 75,000 plants/ha with a Brown-Hardin super seeder (with subsoilers) with 76-cm row spacing.

Nitrogen was applied as NH_4NO_3 at four rates; 0, 37, 75, and 150 kg N/ha in one application, immediately after planting. A post-directed application of paraquat was applied to the corn at the rate of 0.28 kg a.i./ha 5 weeks after emergence.

Clover whole-plant samples were taken just prior to corn planting. Corn was sampled at silk (10 to 15 samples consisting of ear leaf) and again at maturity (whole-plant). All plant samples were dried at 70 C for a minimum of 48 hours prior to weighing, then chopped in a mulching machine (Amerind MacKissic) and ground in a Wiley mill to pass a 1-mm stainless steel screen.

Nitrogen concentration was determined by a microKjeldahl procedure (Bremmer, 1965) as modified by Gallaher et al. (1976). A 100 mg sample of ground plant tissue was placed into a 75-mL digestion tube along with two boiling chips, 3.2 g of catalyst (90% anhydrous K_2SO_4: 10% anhydrous $CuSO_4$) and 10 mL concentrated H_2SO_4. Samples were digested for 3 hours at 380 C (Gallaher et al., 1975b). After they were diluted to 75-mL volume they were analyzed colorimetrically using an autoanalyzer.

Phosphorus, K, Ca, Mg, Cu, Zn, Mn, and Fe concentrations in plant tissue were determined by weighing 1.0 g of ground plant material into a 50-mL pyrex beaker and ashing at 480 C for a minimum of 6 hours. After cooling, 2 mL of concentrated HCl were added to the ash and the mixture was slowly heated until dry. An additional 2 ml of concentrated HCl and approximately 15 mL of water were added to the beakers after cooling. The mixture was covered with a watch glass and digested for 30 minutes on low heat. Solutions were diluted to 100 mL and stored in plastic vials. Phosphorus was determined colorimetrically, K by flame emission spectrophotometry, and the others by atomic absorption spectrophotometry.

Soils were sampled twice, once prior to legume establishment, and again at corn harvest. Soil was sampled to a depth of 20 cm in a single increment except the last sampling date in 1983, when an additional 20 to 40 cm increment was taken. All soil samples were air-dried and sieved to pass a 2-mm screen. Total soil N was determined by the modified microKjeldahl procedure described above, except that a 2 g sample was used. Extracts for mineral analysis were obtained by mixing 5 g soil with 20 ml 0.05 $\underline{M}$ HCl + 0.025 $\underline{M}$ (1/2 H_2SO_4) and shaking 5 minutes before filtration.

Plant content was determined by multiplying concentration of the plant element by total plant dry matter (DM). Soil content was determined by multiplying concentration in the soil by soil weight (2,000,000 kg) in the plow layer of a hectare.

Results and Discussion

Crimson clover DM and nutrient content yields are listed in Table 5.1. Clover was in early bloom at the time of sampling and harvest. Vigorous regrowth of the clover occured even after forage chopping and an application of paraquat and 2,4-D. It appears that clover is an excellent choice for a reseeding winter legume, as demonstrated by Touchton et al.(1982).

Nutrient concentrations in the ear leaf at silk were affected by tillage, except N and Fe, or N rate (Table 5.2). As applied N has been noted to affect ear leaf nutrient concentration in previous studies in which a legume mulch was not utilized it may be that N was available in adequate amounts for maximum concentrations for each nutrient measured. The experimental area had been cropped to another legume, lupine (Lupinus albus L.), for two winters prior to the initiation of this experiment. The residual organic N from these crops in addition to the crimson clover in 1982-1983 probably contributed enough mineralized N for corn uptake through the early silking stage. Conventional-tillage green manure plots had the highest leaf N level, 2.51% while NT stubble plots had the lowest, 2.33%. Iron was the only other nutrient in the ear leaf affected by tillage, being higher with CT green manure than the other treatments.

Corn DM yields were not affected by tillage at the 0.05 level of probability; however, there was a tendency for stubble tratments to respond to applied N through the 150 kg N/ha rate while the NT mulch and CT green manure treatment DM yields were maximum at 75 kg N/ha (Table 5.3). Only Zn was affected by tillage in corn whole plant samples at harvest. Plant concentrations of Zn were 30% higher in NT mulch plots than the other three tillage treatments. Higher levels of soil Zn in the soil surface with NT management have been observed (Hargrove et al., 1982). Corn whole plant DM and nutrient concentrations of N, Ca and Cu were increased with applied N, while P and Zn decreased (Table 5.4). The high soil level of P may have contributed to lower Zn concentrations at the higher yield levels. Phosphorus is known to inhibit translocation of Zn from roots (Stukenholtz et al. 1966) but the decline in P with increasing N rates was not accounted for. Whole plant N concentration was not increased by the addition of 37 kg N/ha bu was higher at the 75 and 150 kg N/ha rates. This was mainly due to a dilution effect as DM yields were increased by 25% with the addition of 37 kg N/ha.

Sorghum seed yields were lowest for CT green manure treatments, which was an unexpected observation (Table 5.6). Incorporation of a green manure is known to hasten N mineralization and corn was responding to N in this experiment. It is possible that incorporating the clover temporarily immobilized some other nutrient (grain P, Mn, and Zn were also lowest for the CT green manure treatment) or perhaps there was an allelopathic effect from the clover residue. Grain yields were not affected by tillage when no N was applied, however maximum grain yields occured with 50 kg N/ha for CT green manure, 75 kg N/ha for NT mulch, and 150 kg N/ha for both stubble treatments.

No-tillage treatments had higher concentrations of P, Ca, Mn, and Fe in corn grain (Table 5.7). Grain Mg levels tended to be higher for unmulched plots. Concentration of Zn in the grain again declined with applied N. Phosphorus was highest at 0 kg N/ha, although N concentration in grain was unaffected by applied N.

Whole plant total N content was not affected by tillage (Table 5.8). Total N content was highest at the 150 kg N/ha rate, 44% higher than with 0 kg N/ha. As maximum DM yields were attained at the 75 kg N/ha rate, the higher N content levels at the 150 kg N/ha rate represent an increase in N concentration of the whole plant only.

Table 5.1. Dry matter and nutrient content yields for crimson clover.

Crop	DM	N	P	Ca	Mg	K	Fe	Mn	Zn	Cu
	kg/ha									
Crimson clover	4300	130	21	52	17	92	0.9	0.2	0.4	0.1

Table 5.2. Nutrient concentrations in corn ear leaf as affected by tillage.

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	%					ppm			
NT mulch	2.35b	0.49a	1.80a	0.52a	0.31a	90b	31a	40a	10a
NT stubble	2.33b	0.53a	1.76a	0.48a	0.30a	90b	32a	40a	11a
CT grn manure	2.52a	0.52a	1.85a	0.48a	0.30a	100a	24a	42a	12a
CT stubble	2.41ab	0.50a	1.78a	0.56a	0.35a	94b	30a	36a	10a

* Tillage means with in a colum followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Table 5.3. Effect of tillage and N rate on corn dry matter (DM).

Tillage system	N rate (kg/ha) 0	37	75	150	MEAN
	DM (mg/ha)				
NT mulch	7.00	9.00	11.00	9.40	9.10 a
NT stubble	7.60	9.10	10.30	11.50	9.60 a
CT grn manure	7.10	9.50	10.40	10.30	9.30 a
CT stubble	6.70	9.50	9.50	10.90	9.10 a
Mean	7.10	9.30	10.30	10.50	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	y=8165 +14.4x	0.32
NT stubble	y=7934 +25.8x	0.90
CT green manure	y=8056 +19.1x	0.62
CT stubble	y=7538 +24.3x	0.79

Table 5.4. Effect of N rate on corn whole plant nutrient concentrations at maturity in a crimson clover/corn system.

N rate	DM	N	P	Ca	Zn	Cu
------kg/ha-------		------------	-%-	------------	-----ppm------	
0	7,060	.60	.48	.28	43	6
37	9,280	.60	.37	.30	36	6
75	10,300	.64	.28	.34	27	6
150	10,510	.69	.26	.37	27	7

Element	Regression equation	R^2
N	$y=.59 +.0006x$	.80
P	$y=.44 -.001x$	.80
Ca	$y=.28 +.0006x$	.91
Zn	$y=40 -.11x$	.74
Cu	$y=6 +.06x$	.68

Table 5.5. Effect of tillage and N rate on corn whole plant N.

Tillage system	N rate (kg/ha) 0	37	75	150	MEAN
	%				
NT mulch	0.60	0.60	0.70	0.73	0.67a
NT stubble	0.58	0.57	0.61	0.67	0.61a
CT grn manure	0.60	0.58	0.65	0.68	0.63a
CT stubble	0.59	0.62	0.63	0.71	0.64a
Mean	0.61	0.60	0.65	0.70	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=0.61 +0.0008x$	0.61
NT stubble	$y=0.57 +0.0006x$	0.87
CT green manure	$y=0.59 +0.0006x$	0.79
CT stubble	$y=0.59 +0.001x$	0.60

Table 5.6. Effect of tillage and N rate on corn grain yield.

	N rate (kg/ha)				
Tillage system	0	37	75	150	MEAN
	kg/ha				
NT mulch	4900a	5700b	7500a	6000b	6000
NT stubble	4500a	6700a	7000a	7500a	6400
CT grn manure	4200a	6300ab	5500b	5500b	5400
CT stubble	4600a	4700c	6000b	7400a	5700
Mean	4500	5900	6500	6600	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=5533 +7.6x$	0.21
NT stubble	$y=5286 +17.4x$	0.71
CT green manure	$y=4699 +17.3x$	0.38
CT stubble	$y=4345 +19.9x$	0.93

Table 5.7. Affect of tillage on corn grain nutrient concentrations in a crimson clover/corn system.

	P	Ca	Mg	Fe	Mn
	-----	---%	-----	---ppm	---
NT mulch	0.37a	0.38a	0.098b	130a	35a
NT stubble	0.37a	0.27ab	0.104a	140a	34a
CT grn manure	0.32b	0.25ab	0.097b	110ab	18b
CT stubble	0.33b	0.20b	0.100ab	80b	28a

* Tillage means within a column followed by the same letter do not differ at the .05 level for Duncan's Multiple Range Test.

** NT = no-tillage and CT = conventional tillage

Table 5.8. Effect of tillage and N rate on corn N content.

	N rate (kg/ha)				
Tillage system	0	37	75	150	MEAN
	kg/ha				
NT mulch	46	55	78	69	62a
NT stubble	44	52	63	77	59a
CT grn manure	42	55	68	70	59a
CT stubble	39	59	60	77	59a
Mean	43	55	67	73	

* Tillage means within a column followed by the same letter do not differ significantly at the 0.05 level of probability according to Duncan's Multiple Range Test.

Tillage	Regression equation	R^2
NT mulch	$y=51.4 +0.16x$	0.53
NT stubble	$y=44.4 +0.22x$	0.96
CT green manure	$y=46.8 +0.18x$	0.80
CT stubble	$y=43.7 +0.23x$	0.90

CHAPTER 6
WINTER CROP MANAGEMENT FOR GRAIN SORGHUM

Introduction

Utilization of winter crops as a mulch, green manure, or hay crop in succession with corn (*Zea mays* L.) or grain sorghum (*Sorghum bicolor* L. Moench) is a growing trend in the southern US. No-tillage (NT) seedbed preparation for the summer grain crop is also popular, largely because it facilitates timely spring planting and may help conserve soil moisture due to the mulching effect.

Residues from a winter crop do not have to be soil-incorporated for N mineralization (Schrader et al., 1956), although the mineralization will likely be faster under conventional-tillage (CT) management than with NT (Smith, 1979 and Eylands and Gallaher, 1984). In addition, there is some evidence that denitrification (Smith et al., 1980) and leaching (Thomas et al., 1979) losses of N may be higher under NT management. Despite these observations, soil N and OM are frequently built up or better maintained under NT compared to CT (Blevins et al., 1977 and Lal, 1976).

Grain sorghum seed yields have been found to be similar under NT and CT when good management practices are followed (Nelson et al., 1977). As grain sorghum is grown primarily as a dryland crop, response to increased soil moisture and N mineralized from a winter cover crop might be expected. Winter grains such as rye (*Secale cereal* L.) may be grazed early in the winter and subsequently utilized for grain, surface mulched, or green manured prior to sorghum planting. Winter legumes are rarely grazed but may be harvested as a high quality hay in addition to mulching or green manuring. Touchton et al. (1982) removed crimson clover (Trifolium incarnatum L.) prior to establishing grain sorghum and only lowered seed yields in one year of a 3-year study.

Hairy vetch (Vicia villosa Roth) was found to provide 90 to 100 kg N/ha to a NT corn crop, significantly more than a crimson clover or rye cover crop in Kentucky (Ebelhar et al., 1984). If a winter legume is able to serve as a mulch and N source, fertilizer inputs and nutrient losses to erosion may be reduced.

It was the objective of this study to determine the effect of winter crops and their management on optimum N fertilization rates for grain sorghum. No-tillage and CT seedbed prepartion of the sorghum seedbed were compared as to their influence on N uptake and yield by grain sorghum.

Materials and Methods

The experiment was conducted in 1978 and 1979 on an Arredondo fine sand, a member of the loamy silicious hyperthermic family of the Grossarenic Paleudults. The soil is fairly well-drained but has a slightly compacted layer between 20 to 30 cm and is high in residual phosphates. The experimental area had been in Bahiagrass sod for four years prior to this study.

The experiment utilized a randomized complete split-split plot design with four replications. Main treatments consisted of four winter crops; rye (Secale cereal L.), lupine (Lupinus angustifolius L.), Bahiagrass (Paspalum notatum L.) sod, and fallow. Additionally, lupine and rye, with winter growth harvested and removed prior to sorghum seeding were included for a total of six main treatments. Split-plots were NT and CT prepartion of the sorghum seedbed following the winter crop. Split-split plots consisted of five rates of N fertilizer; 0, 25, 50, 100, and 200 kg N/ha.

The cropping system was undisturbed Bahia sod, fall-plowed Bahia sod, or fall-planted rye or lupine, followed by grain sorghum. Lupine (cultivar 'Frost') was seeded at 50 kg seed/ha and rye ('Wrens abruzzi') was seeded at 100 kg seed/ha. The soil was moldboard plowed and harrowed two times before winter crop establishment in the case of lupine and rye. Lupine and rye were planted in 25-cm rows with a Tye drill. Potassium, Mg, and S were applied at planting according to soil test recommendations. No herbicides were employed on the winter crops. In the spring, rye and lupine were sampled for DM yield and nutrient concentration, then mowed to a height of 7 cm and removed or left standing as the treatment dictated. The rye and lupine mulches were killed (on NT plots) with an application of paraquat (1,1', dimethyl, 4,4' bipyridinium ion present as the dichloride salt plus 236 mL Ortho X77 surfactant/378 L water) and 2, 4-D (2,4-dichlorophenoxy acetic acid) immediately following sorghum planting. May-planted grain sorghum (cultivar Goldkist 'GK 802G') was seeded at 9 kg/ha with a Brown-Hardin Super Seeder with 76-cm row spacings.

Nitrogen was applied as NH_4NO_3 at five rates; 0, 25, 50, 100, and 200 kg N/ha in split applications, the first immediately after planting and the second 4 weeks later. A post-directed application of paraquat was applied to the sorghum at the rate of 0.28 kg a.i./ha 5 weeks after emergence.

Winter crop whole-plant samples were taken just prior to sorghum planting. Grain sorghum was sampled at early heading (10 to 15 samples consisting of 3rd leaf from the head) and again at maturity (whole-plant). All plant samples were dried at 70 C for a minimum of 48 hours prior to weighing, then chopped in a mulching machine (Amerind MacKissic) and ground in a Wiley mill to pass a 1-mm screen.

Nitrogen concentration was determined by a microKjeldahl procedure (Bremmer, 1965) as modified by Gallaher et al. (1976). A 100-mg sample of ground plant tissue was placed into a 75-mL digestion tube along with two boiling chips, 3.2 g of catalyst (90% anhydrous K_2SO_4, 10% anhydrous $CuSO_4$) and 10 mL concentrated H_2SO_4. Samples were digested for 3 hours at 380 C (Gallaher et al., 1975b). After they were diluted to 75-mL volume they were analyzed colorimetrically using an autoanalyzer.

Phosphorus in plant tissue was determined by weighing 1.0 g of ground plant material into a 50-mL pyrex beaker and ashing at 480 C for a minimum of 6 hours. After cooling, 2 mL of concentrated HCl were added to the ash and the mixture was slowly heated until dry. An additional 2 mL of concentrated HCl and approximately 15 mL of water were added to the beakers after cooling. The mixture was covered with a watch glass and digested for 1/2 hour on low heat. Solutions were diluted to 100 mL and stored in plastic vials. Phosphorus was determined colorimetrically.

Soils were sampled twice during each cropping year, once prior to the winter crop and again at sorghum harvest. Soil was sampled to a depth of 20 cm in a single increment. All soil samples were air-dried and sieved to pass a 2-mm screen. Plant content was determined by multiplying concentration of the plant element by total plant dry matter (DM). Soil content was determined by multiplying concentration in the soil by soil weight in the plow layer of a hectare.

Statistical analyses included analysis of variance for a split plot design. Significantly different tillage means were separated by the Duncan's Multiple Range Test for significance at the 0.05 level of probability. Regression analyses were performed on responses affected by N rate.

Results and Discussion

Rye and lupine DM, N concentration at harvest, and total N content are given in Table 6.1. Although DM yields for both were similar, N concentration was higher for lupine, resulting in total N contents of over twice that of rye. It would also be expected from these data that C:N ratio in lupine would be more favorable for net N mineralization .

Overall analysis of variance indicated strong interactions between crop and tilllage, and crop and N rate for grain sorghum DM and seed yields, but not for whole N concentration at maturity. Data for tillage effects within crops appear in Table 6.2. Incorporating the Bahiagrass sod resulted in higher DM and seed yields for sorghum. As the experimental field had been in Bahiagrass for 4 years prior to the study, it was felt that the tillage operation promoted mineralization of the massive root system that was present at the beginning of the experimental period. As the Bahiagrass did exhibit some regrowth during sorghum development, increased competition from regrowth was noted on NT plots. The Bahiagrass root system also inhibited sorghum stand establishment, a factor that must be considered throughout this experiment. For fallow treatments, the Bahiagrass sod had been incorporated the previous fall, giving the root system time to mineralize and for soil C:N ratios to equilibrate. Subsequently there was no yield differences for either DM or seed yields due to tillage of fallow plots.

As opposed to the Bahiagrass sod and fallow treatments, rye and lupine residue from winter growth were either left or removed prior to tillage. Both sorghum DM and seed yields were highest for the CT green manure treatment when following lupine. Seed yields reached similar maximum levels for NT mulch and CT green manure treatments, but those levels were attained at a lower rate of applied N if lupine residue was incorporated. This suggests that incorporation of the legume may be necessary for maximum recovery of N mineralized from the legume and that slightly more inorganic N must be added to the system if the mulching and other benefits of a NT system are deemed more important than the additional N recovered under CT management. The additional increment of N required of the NT system to produce yields of the same magnitude of CT was approximately 25 kg N/ha.

Method of tillage or clover residue removal did not affect DM or seed yield of sorghum when following rye. The lower N content and slower mineralization of rye residue may account for this observation.

Data for cropping differences within tillage systems are given in Table 6.3. Bahiagrass sod and fallow CT and NT treatments were grouped with CT stubble and NT stubble and NT stubble treatments of rye and lupine for analysis as there was no winter crop residue to be removed. Sorghum DM and seed yields were lower following Bahia sod than for other treatments. Seed yields were higher following lupine or rye stubble than if no winter crop were grown for NT.The same trend existed for CT, although it was not different at the 0.05 level of significance. When clover residue was incorporated, sorghum DM and seed yields were higher following lupine than rye, probably due to a greater quantity of mineralized N. If the lupine residue was left on the surface as a NT mulch, however, no differences were detected for sorghum DM or grain yields following rye or lupine.

Regression analyses were performed on those systems influenced by applied N. Prediction equations and R^2 values for grain sorghum DM, seed yield, and whole plant N concentration at maturity appear in Tables 6.4, 6.5, and 6.6, respectively. Applied N did not affect sorghum DM yields when following CT green manure treatments of rye or lupine, presumably due to sufficient quantities of mineralized N. Most responses were of a quadratic nature as DM, seed yield, and N concentration all tended to increase rapidly at low rates of applied N, then level off at approximately 100 kg N/ha. Seed yields were not affected by applied N only in the case of the CT green manure treatment following lupine.

Regression coefficients tended to be higher for stubble treatments than if a winter crop residue was left.

Table 6.1. Rye and lupine dry matter, N concentration, and total content yields.

	DM	N%	N content
	--kg/ha--	--%--	--kg/ha--
Rye	2760	1.6	44
Lupine	2600	3.9	101

Table 6.2. Grain sorghum dry matter and seed yields as affected by tillage for four winter cropping systems.

Crop	Tillage	DM	Seed yield
		kg/ha	kg/ha
Bahia sod	NT	4440b	2140b
	CT	5260a	2710a
Fallow	NT	5910a	3370a
	CT	5930a	2930a
Lupine	NT mulch	6020bc	3250b
	NT stubble	5220c	3300b
	CT grn manure	7020a	4070a
	CT stubble	6320ab	3120b
Rye	NT mulch	5640a	3210a
	NT stubble	5700a	3430a
	CT grn manure	5500a	3160a
	CT stubble	5980a	3120a

* Tillage means within each crop followed by the same letter are not significantly different at the 0.05 level according to Duncan's Multiple Range Test.

** NT = no-tillage and CT = conventional tillage

Table 6.3. Grain sorghum dry matter and seed yields as affected by winter crop for four tillage systems.

Tillage	Crop	DM	Seed yield
		----------kg/ha--------	
NT mulch	Rye	5640a	3210a
	Lupine	6020a	3250a
NT stubble	Rye	5700ab	3430a
	Lupine	5220b	3300a
	Bahia sod	4640c	2250b
	Fallow	5880a	2610b
CT green manure	Rye	5500b	3160b
	Lupine	7020a	4070a
CT stubble	Rye	5980a	3120a
	Lupine	6320a	3120a
	Bahia sod	5320b	2660a
	Fallow	6060a	2840a

* Crop means within each tillage system followed by the same letter are not significntly different at the 0.05 level according to Duncan's Multiple Range Test.

Table 6.4. Regression analysis for sorghum dry matter yield at maturity as affected by N fertilization.

Crop	Tillage	Prediction equation	R^2
Bahia sod	NT	$y=1.29 +0.02x -0.00006x^2$	0.61
	CT	$y=1.43 +0.03x -0.00006x^2$	0.55
Fallow	NT	$y=1.47 +0.04x -0.0001x^2$	0.82
	CT	$y=2.00 +0.03x -0.0001x^2$	0.64
Rye	NT mulch	$y=1.86 +0.03x -0.0001x^2$	0.80
	NT stubble	$y=1.99 +0.01x -0.000006x^2$	0.74
	CT green manure	$y=1.87 +0.03x -0.0001x^2$	0.44
	CT stubble	$y=2.00 +0.02x +0.00004x^2$	0.78
Lupine	NT mulch	$y=2.34 +0.02x -0.00008x^2$	0.51
	NT stubble	$y=2.04 +0.01x -0.00004x^2$	0.60
	CT green manure	--------NS----------	
	CT stubble	$y=2.42 +0.02x -0.00009x^2$	0.54

* NT = no-tillage and CT = conventional tillage.

Table 6.5. Regression analysis for seed yield as affected by N fertilization.

Crop	Tillage	Prediction equation	R^2
Bahia sod	NT	$y=793 + 27.3x - 0.08x^2$	0.64
	CT	$y=1187 + 43.0x - 0.16x^2$	0.65
Fallow	NT	$y=1141 + 34.3x - 0.10x^2$	0.75
	CT	$y=1983 + 21.0x - 0.05x^2$	0.75
Rye	NT mulch	$y=1589 + 40.1x - 0.13x^2$	0.70
	NT stubble	$y=1366 + 55.1x - 0.19x^2$	0.85
	CT green manure	$y=1672 + 43.0x - 0.16x^2$	0.59
	CT stubble	$y=1411 + 36.6x - 0.10x^2$	0.80
Lupine	NT mulch	$y=2573 + 27.9x - 0.13x^2$	0.39
	NT stubble	$y=1750 + 36.8x - 0.11x^2$	0.82
	CT green manure	--------NS----------	
	CT stubble	$y=2050 + 29.5x - 0.11x^2$	0.48

* NT = no-tillage, CT = conventional tillage

Table 6.6. Regression analysis for sorghum whole plant N concentration at maturity as affected by N fertilization.

Crop	Tillage	Prediction equation	R^2
Bahia sod	NT	$y=0.73 +0.002x +0.000004x^2$	0.80
	CT	$y=0.80 +0.003x -0.000003x^2$	0.73
Fallow	NT	$y=0.89 +0.002x -0.000002x^2$	0.78
	CT	$y=0.86 +0.003x -0.000002x^2$	0.85
Rye	NT mulch	------------NS-----------	
	NT stubble	$y=0.80 +0.002x -0.000008x^2$	0.86
	CT green manure	$y=0.92 +0.004x -0.000007x^2$	0.84
	CT stubble	$y=0.93 +0.003x -0.000004x^2$	0.67
Lupine	NT mulch	$y=0.91 +0.005x -0.00001x^2$	0.75
	NT stubble	$y=0.86 +0.002x -0.000004x^2$	0.89
	CT green manure	$y=0.86 +0.0007x -0.00002x^2$	0.80
	CT stubble	$y=0.90 +0.002x -0.000005x^2$	0.75

* NT = no-tillage and CT = conventional tillage

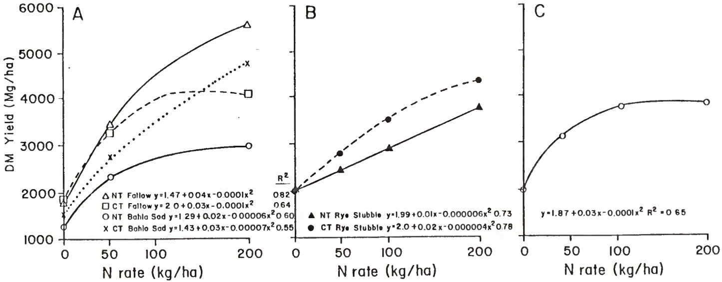

Fig. 6.1. Relation between applied N and grain sorghum dry matter (DM) yield as affected by tillage.

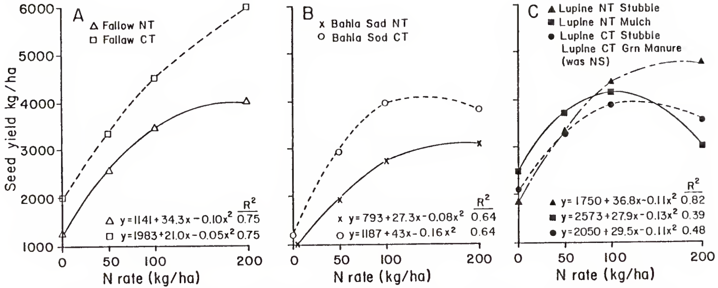

Fig. 6.2. Relation between applied N and grain sorghum seed yield as affected by tillage.

CHAPTER 7
SUMMARY

As the world's population continues to increase more rapidly than food production, the utilization of multicropping systems to exploit fully the potential of existing arable land is being thoroughly investigated. The ecosystem of an agricultural soil is delicately balanced, however, and productive soils can easily be ruined if intensive cropping systems are not coupled with proper soil management. Since cereal grains are the staple of man's existence and N is the most common yield-limiting nutritional factor to cereal production, ways of providing an inexpensive source of N are of great interest.

Including legumes in multicropping systems with cereal grains has proven to be at least a partial solution to this problem. Legumes grown in the "off season" may provide erosion control, mulching benefits, improve nutrient cycling, and will provide some measure of organic N to the soil that will eventually mineralize for utilization by a following cereal grain. It was the purpose of this study to investigate several legume/cereal grain systems in Florida and determine how the legume management and tillage of the cereal seedbed affected N fertilization rates for optimum grain production.

Both crimson clover and lupine fixed enough atmospheric N for maximum grain sorghum or corn production under dryland conditions. However, only a portion of the total was mineralized for uptake. Crimson clover was not as fibrous as lupine and appeared to mineralize more quickly, although lupine produced greater DM and total N. Corn or sorghum following crimson clover still responded to applied N.

Throughout the study, sorghum seed yields responded to applied N more when following lupine than when following crimson clover and more when NT seedbed preparation was used than if CT was employed. Both of these trends were probably due to the rate of mineralization of N in the legume residue. The lower C:N ratio of clover as compared to lupine and the improved soil-legume residue contact in CT as opposed to NT would both encourage more rapid mineralization and better recovery of this N by grain sorghum or corn.

Incorporation of legume residue is not necessary to release N, however, and the benefits of no-tillage systems such as reduced energy costs and improved soil moisture under mulches may offset the slightly higher N requirements of a NT system. Removing the legume residue as a forage increased the amount of applied N necessary for optimum sorghum seed yield, yet the value of the forage would easily offset the cost of the additional fertilizer inputs.

Nutrient cycling in such double-cropping systems is also improved through reduced erosional and leaching losses and through nutrients brought to the soil surface from the deeper rooting legumes.

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APPENDIX

Table A.1. Soil test results following a crimson clover/grain sorghum cropping system for the no-tillage-mulch treatment.

Depth	N rate	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
	--kg/ha--		kg/ha									
0 - 20 cm	0	5.9	1023	127	61	660	119	703	36	3.6	2.6	6.6
	25	5.7	959	131	65	612	94	744	34	3.6	2.8	6.7
	50	5.6	1204	126	68	444	76	672	32	3.6	3.0	7.2
	75	5.5	485	139	77	408	71	792	37	4.8	2.5	9.0
	100	5.5	1005	109	54	420	67	720	40	3.6	2.8	6.6
	150	5.5	1014	128	78	408	74	696	38	3.6	3.5	7.3
	200	5.4	1002	118	62	408	64	708	40	3.6	3.4	7.2
20 - 40 cm	0	5.9	532	104	26	456	73	732	41	2.4	1.6	4.4
	25	5.8	649	118	36	600	85	780	36	3.6	1.8	5.6
	50	5.6	573	102	44	420	65	720	34	3.6	2.3	5.8
	75	5.6	532	120	24	324	48	888	46	3.6	1.7	6.5
	100	5.6	532	90	29	300	50	768	43	2.4	1.3	5.3
	150	5.6	546	128	31	324	52	780	46	2.4	2.0	5.2
	200	5.4	611	104	31	360	50	780	44	3.6	3.0	5.6

Table A.2. Soil test results following a crimson clover/grain sorghum cropping system for the no-tillage-stubble treatment.

Depth	N rate	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
	--kg/ha--		kg/ha									
0 - 20 cm	0	6.0	952	202	88	564	104	720	43	4.8	3.2	7.6
	25	5.6	1052	137	91	444	82	732	41	6.0	4.9	7.3
	50	5.7	833	137	109	432	89	684	41	6.0	3.1	7.4
	75	6.2	965	156	79	576	94	720	37	4.8	3.2	6.7
	100	5.7	953	144	83	540	100	708	37	4.8	3.8	7.4
	150	5.4	941	160	86	516	86	744	40	3.6	3.2	7.4
	200	5.3	923	142	92	552	68	732	38	4.8	3.2	7.9
20 - 40 cm	0	6.0	605	182	38	552	83	840	46	3.6	2.2	6.4
	25	5.8	502	103	29	324	54	768	41	3.6	1.6	5.6
	50	5.8	496	110	32	324	54	732	46	3.6	1.8	5.4
	75	6.7	565	112	35	504	79	768	42	2.4	1.4	5.2
	100	5.8	585	113	32	408	64	732	38	3.6	2.5	5.8
	150	5.4	523	121	32	420	67	816	43	2.4	1.6	5.4
	200	5.5	580	110	28	432	68	768	40	3.6	1.7	5.6

Table A.3. Soil test results following a crimson clover/grain sorghum cropping system for the conventional tillage-green manure treatment.

Depth	N rate	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
	--kg/ha--		--------kg/ha--------									
0 - 20 cm	0	5.4	958	157	74	516	92	696	36	6.0	3.5	6.4
	25	5.4	1029	133	100	420	85	720	40	4.8	3.1	7.7
	50	5.7	1029	199	89	564	84	744	38	6.0	3.7	7.3
	75	5.4	1057	188	85	480	79	720	41	4.8	3.6	7.9
	100	5.7	984	119	71	432	76	672	37	4.8	2.8	6.5
	150	6.0	1033	119	80	300	55	636	38	4.8	1.7	6.2
	200	5.9	1054	126	70	456	76	672	35	4.8	2.9	7.0
20 - 40 cm	0	5.5	519	121	43	372	64	744	42	6.0	1.7	5.2
	25	5.6	590	120	43	336	64	840	44	4.8	1.4	5.8
	50	5.7	562	211	48	588	72	840	48	4.8	1.8	6.2
	75	5.6	483	164	30	444	46	840	32	3.6	1.0	6.0
	100	5.8	512	103	30	300	55	732	40	3.6	1.6	5.0
	150	5.9	577	96	60	312	52	636	36	4.8	2.2	5.6
	200	6.0	565	102	29	360	50	708	35	3.6	1.6	5.2

Table A.4. Soil test results following a crimson clover/grain sorghum cropping system for the conventional tillage-stubble treatment.

Depth	N rate	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
	--kg/ha--		kg/ha									
0 - 20 cm	0	6.0	1007	145	86	612	104	708	36	4.8	3.2	7.1
	25	5.8	1099	132	168	516	80	660	37	4.8	4.7	7.0
	50	5.7	1007	133	73	442	86	684	40	6.0	3.7	6.7
	75	5.8	984	131	71	516	90	684	36	4.8	3.8	7.0
	100	5.9	1068	161	58	636	90	732	38	6.0	3.6	7.2
	150	5.7	1030	145	98	432	74	720	38	4.8	3.0	7.7
	200	5.8	993	127	104	576	76	648	42	4.8	2.8	6.0
20 - 40 cm	0	5.8	583	118	35	456	76	792	43	3.6	1.3	5.8
	25	5.9	623	110	28	420	70	720	41	4.8	1.2	5.5
	50	5.9	558	127	31	444	80	792	53	3.6	1.1	5.0
	75	6.0	592	110	28	480	77	756	37	4.8	1.4	5.0
	100	5.9	562	172	28	588	85	804	44	3.6	1.6	5.9
	150	5.6	524	138	31	468	56	888	49	3.6	1.4	5.8
	200	5.8	589	119	48	468	56	708	54	2.4	1.2	4.6

Table A.5. Soil test results following a lupine/grain sorghum cropping system for the no-tillage-mulch treatment.

Depth	N rate	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
	--kg/ha--		kg/ha									
0 - 20 cm	0	5.4	1038	90	120	528	79	624	35	9.2	3.2	5.8
	25	5.3	1014	94	101	540	78	744	37	7.2	2.9	6.2
	50	5.3	1091	89	108	480	73	696	37	6.0	3.5	5.8
	75	5.3	1067	92	95	444	68	720	36	4.8	3.7	6.0
	100	5.3	1080	89	85	432	74	588	40	4.8	3.1	5.3
	150	5.3	1094	86	114	492	71	612	38	6.0	3.1	5.3
	200	5.6	1152	89	107	396	54	612	41	6.0	3.8	6.0
20 - 40 cm	0	5.3	668	67	49	444	58	708	36	6.0	2.3	4.4
	25	5.3	622	82	30	348	53	768	40	6.0	1.3	4.8
	50	5.2	721	67	36	456	62	744	35	4.8	1.6	4.7
	75	5.3	699	89	50	492	61	756	37	4.8	2.2	5.3
	100	5.3	617	70	34	324	47	672	37	3.6	1.4	3.8
	150	5.1	706	67	38	372	48	636	37	4.8	1.7	4.3
	200	5.9	702	72	29	384	48	708	38	3.6	1.3	4.3

Table A.6. Soil test results following a lupine/grain sorghum cropping system for the no-tillage-stubble treatment.

Depth	N rate	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
	--kg/ha--		kg/ha									
0 - 20 cm	0	5.7	911	100	116	468	91	660	41	4.8	2.8	5.4
	25	5.9	951	107	126	564	104	648	37	4.8	3.0	5.8
	50	5.6	1027	100	88	516	90	684	38	4.8	3.1	5.9
	75	6.1	1129	95	102	684	107	756	38	9.8	3.6	6.6
	100	6.0	1051	108	103	528	84	732	37	7.2	4.7	7.0
	150	6.0	1044	108	122	444	73	756	38	6.0	4.7	7.1
	200	6.0	968	101	121	468	72	780	37	6.0	4.0	7.0
20 - 40 cm	0	5.7	523	84	54	348	66	804	46	4.8	1.6	4.7
	25	5.9	598	82	37	444	66	744	36	4.8	1.6	4.4
	50	5.5	615	79	29	360	60	744	38	4.8	1.6	4.7
	75	6.1	609	73	42	504	74	780	35	9.6	2.3	5.3
	100	6.0	662	91	34	588	59	864	37	6.0	4.3	5.9
	150	6.1	619	89	46	432	66	816	37	4.8	2.8	5.4
	200	6.2	598	80	29	396	59	852	40	4.8	2.2	5.3

Table A.7. Soil test results following a lupine/grain sorghum cropping system for the conventional tillage-green manure treatment.

Depth	N rate	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
	--kg/ha--		kg/ha									
0 - 20 cm	0	5.8	1076	102	115	528	106	744	38	4.8	4.4	6.1
	25	5.9	1059	83	86	540	90	612	36	4.8	3.6	4.7
	50	6.2	980	89	132	468	88	648	37	3.6	3.0	5.3
	75	6.1	1043	94	127	564	90	648	35	4.8	4.6	6.0
	100	6.0	1099	106	133	480	77	660	41	242	3.6	6.6
	150	5.7	1101	95	144	408	66	660	41	6.0	3.5	6.1
	200	6.0	1122	97	168	468	97	624	40	6.0	3.4	5.8
20 - 40 cm	0	5.9	607	67	55	420	70	744	38	3.6	3.0	4.2
	25	5.8	637	67	67	444	74	660	36	4.8	3.1	4.3
	50	6.1	671	71	48	372	55	660	38	4.8	2.3	4.2
	75	6.0	644	74	44	444	68	684	36	4.8	2.0	4.7
	100	5.8	720	84	46	384	62	768	42	6.0	3.2	4.3
	150	5.9	685	76	53	384	55	720	41	4.8	1.7	4.1
	200	6.1	638	80	67	456	76	720	43	4.8	1.4	4.2

Table A.8. Soil test results following a lupine/grain sorghum cropping system for the conventional tillage-stubble treatment.

Depth	N rate	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
	--kg/ha--		kg/ha									
0 - 20 cm	0	6.2	1073	108	73	552	78	648	40	4.8	2.6	8.2
	25	6.1	1140	114	89	612	85	648	37	4.8	3.2	6.4
	50	6.1	1034	108	61	588	83	648	38	4.8	3.7	5.9
	75	5.9	1096	104	83	492	66	588	41	9.6	4.6	6.4
	100	6.0	1045	98	84	492	68	624	37	4.8	2.9	5.3
	150	6.1	1018	119	103	528	70	588	37	6.0	3.6	6.2
	200	6.1	1063	109	92	612	78	648	37	6.0	3.8	6.4
20 - 40 cm	0	6.2	682	91	29	372	49	708	40	4.8	4.2	4.4
	25	6.2	633	88	36	552	74	708	38	4.8	1.7	4.8
	50	6.2	597	83	26	444	64	684	40	4.8	1.3	4.2
	75	6.0	667	91	26	420	54	684	38	4.8	1.8	4.7
	100	6.1	635	84	31	492	61	672	37	4.8	1.7	4.0
	150	6.2	784	92	43	528	55	660	35	4.8	1.7	4.4
	200	6.2	688	88	30	540	68	720	37	6.0	2.2	4.7

Table A.9. Soil test results for samples taken prior to a crimson clover/grain sorghum cropping system.

Block	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
		kg/ha									
1	5.9	1189	134	98	516	91	564	47	3.6	3.2	9.8
2	5.9	1052	145	64	660	90	588	42	3.6	3.5	9.8
3	6.0	9513	116	56	660	91	576	32	3.6	3.4	10.1
4	6.0	8766	100	43	528	74	540	30	3.6	2.8	7.2
5	5.9	9805	108	48	420	68	552	34	3.6	3.1	8.5

Table A.10. Soil test results for samples taken prior to a lupine/grain sorghum cropping system.

Block	pH	N	P	K	Ca	Mg	Al	Fe	Cu	Zn	Mn
		kg/ha									
1	5.9	1025	102	85	660	97	564	32	6.0	2.8	8.8
2	5.6	1093	92	82	468	84	600	36	3.6	3.0	8.5
3	5.8	1013	102	102	516	83	624	36	6.0	2.4	6.4
4	5.8	1046	91	110	444	89	636	37	9.6	2.9	8.3
5	6.0	1055	100	76	492	83	624	35	6.0	3.0	9.6

BIOGRAPHICAL SKETCH

Val Jon Eylands was born on 14 August 1952 in Rugby, North Dakota. He received his B.S. degree from the University of North Dakota in 1975 and his M.S. degree from North Dakota State University in 1977. He served as as an agricultural extension agent for the Department of Land Development in the US Peace Corps, Thailand, from 1977 to 1979. He and his wife, Juanita, of Fargo, North Dakota, then moved to Minnesota where Val was an instructor of soils at the University of Minnesota, Crookston. In 1980 he was hired as an agronomist for Dahlgren and Co., a Minnesota-based hybrid sunflower company. He came to the University of Florida in 1982 and expects to receive his PhD in Agronomy in April, 1984. Upon completion of his degree, Val will take a position with the International Programs Office of the University of Illinois and will work two years as a production agronomist for the ZAMARE project (funded by USAID) at the Mt. Makulu research station in Zambia, Africa.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Raymond N Gallaher

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This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

April, 1984

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